Astronomers of To-Day

Hector Macpherson (Junior)

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of To-Day : :

Sir William Huggins.

Astronomers of To-Day

AND THEIR WORK

BY

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WITH TWENTY-SEVEN PORTRAITS.

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TO

My Father and Mother.

PREFACE.

WITH two exceptions, the sketches of which this volume is composed originally appeared as weekly contributions to an Edinburgh newspaper. The number might have been largely augmented, but in order to bring the book within reasonable compass, it was found necessary to adopt an age-limit.

The writer has to thank the distinguished astronomers for supplying the biographical details, for reading and correcting the articles, supplying the various portraits, and generally for their kindly interest in the work. The obligations of the writer are also due to the valuable works of Miss Clerke, and to that encyclopædia of astronomical information—the *Monthly Notices* of the Royal Astronomical Society of London.

March 1905.

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ASTRONOMERS OF TO-DAY.

Otto Wilhelm von Struve

THE oldest of the great astronomers of the present day is the venerable Otto Struve, formerly director of the great Russian Observatory at Pulkowa near St. Petersburg. Otto Struve is the sole representative of a past generation, when he was the contemporary of Le Verrier, of Secchi, of Adams, of Faye. Although Professor Struve's services to astronomy are completed, yet, as Professor Turner has well remarked, his name remains to testifiy that "devotion to astronomy enables men to defy the march of years."

Otto Wilhelm von Struve, the distinguished son of a distinguished father, was born at Dorpat, on May 7, 1819. Although by birth a Russian, he is German by descent. His father, Friedrich Georg Wilhelm Struve, the first of a race of astronomers, born at Altona in 1793, went to study in the new University of Dorpat, and was, at the age of twenty, appointed director of the Observatory there. In 1839 he was appointed director of the great observatory at Pulkowa, near St. Petersburg, where he remained until his retirement in 1861.

The elder Struve was specially devoted to sidereal astronomy, chiefly double stars. In this branch of research he was followed by his son Otto, who was, at a very early age appointed assistant to his father. He was twenty-two years old when he made his first elaborate investigation, on the movement of the Solar System through space. It had been shown by Herschel, in

1783 and 1805, that the Sun, carrying with it the planets and comets, was moving towards a point in the constellation Hercules. Astronomers of the next generation, among them Sir John Herschel and Bessel, rejected the theory, which was, however, confirmed in 1837 by Argelander, from observations made at Abo, in Finland.

In order to test Argelander's work, Otto Struve, in 1841, undertook to solve the question. In his investigation he made use of the motions of four hundred stars, and reached a conclusion as to the position of the solar apex closely agreeing with that found by Herschel in 1783. He also studied the velocity of the Solar System, and concluded that if the Sun were revolving round some central body placed at a distance equal to that of stars of the first magnitude, no less than three million years would be required for it to accomplish a revolution. Dr. Struve's researches on the subject were published five years before Mädler propounded his theory of the solar motion round the Pleiades, an idea which was rejected by the Struves.

In 1842, M. Struve observed the total solar eclipse of July 8 of that year from Lipeszk, and noted the great brilliancy and extent of the corona. He was also one of those who observed the solar prominences, the others being Airy and Baily of England, and Arago of France. In 1842, of course, the spectroscope was unknown, and the observation of the solar prominences was made by direct methods on the rare occasions of solar eclipses.

Like his father, M. Struve soon proved himself a specialist in double stars. One of his first discoveries was in 1842, when he divided γ Andromedæ with the Pulkowa refractor of 15 inches aperture. He discovered a large number of interesting double stars, chief among them δ Equulei, of which the components are of the 4th and 5th magnitude respectively. Both stars revolve round their centre of gravity in a period between five and eleven years, so that several revolutions have been completed since its discovery in 1852. Altogether M. Struve discovered five hundred double stars,

and constructed a catalogue of his discoveries. In recognition of his work the Royal Astronomical Society in 1848 elected him an Associate, and in 1850 awarded him the gold medal.

The brilliant young astronomer had already acquired considerable fame when, in 1847, he observed, with the Pulkowa refractor, the satellite of Neptune, which was discovered by Lassell. In 1847, on October 8, he detected a satellite of Uranus, independently discovered by Lassell. The satellite, which received the name of Umbriel, is the second in order of distance from Uranus, round which it revolves in 4 days, 3 hours, at a mean distance of about 173,000 miles.

A startling theory of the rings of Saturn was propounded by Otto Struve in 1851. Comparing his measurements on the rings made at Pulkowa, in 1850 and 1851, with those of various other astronomers since the time of Huyghens, he reached the conclusion that while the edge of the outer ring remained at the same distance from the globe of Saturn, the inner diameter of the ring was decreasing at the rate of a little over one second of arc per century, or sixty miles a year. In other words, the bodies composing the rings were being drawn closer to the planet. M. Struve calculated that, at this rate, only three centuries would be required to bring about the precipitation of the ring-system on the ball of the planet. On this hypothesis, a farther decrease in the distance between the planet and the inner edge of the ring might be looked for within the next thirty years. In 1881 and 1882, accordingly, M. Struve made a second series of measures, but the actual was much less than the hypothetical decrease. Recent measures, by other astronomers, confirm M. Struve's later measures, and accordingly his earlier theory has been abandoned. All the same, the theory stimulated interest in the Saturnian system, and did good service to astronomy.

In the course of his observations on the rings, M. Struve proposed the nomenclature by which they are now known. The bright ring, exterior to the division known as Cassini's, is A; interior to this is B, while the dusky ring discovered in 1850 is C.

In 1851 Professor Struve discovered the relative variability of the double star γ Virginis. The components of this binary star are generally of the third magnitude. Periodically, each in turn diminishes in brilliance by about half-a-magnitude, regaining its former light in a few days. Professor Struve, however, was unhopeful of successfully investigating the variations of a star which rises only thirty degrees above the horizon of Pulkowa. Professor Struve also discovered the relative variability of one of his own double stars, known as Otto Struve 256.

Like his father, Otto Struve has been one of the most persevering searchers after stellar parallax. Observations of this kind were commenced at Pulkowa in the fifties. At that time, comparatively few measurements had been made. In 1852 Struve commenced a series of measures on 61 Cygni, the parallax of which was first measured by Bessel in 1837. He found that 61 Cygni was separated from our Solar System by about forty billions of miles, a result which was confirmatory of Bessel's, and has been confirmed by the late Professor Pritchard, and Sir Robert Ball. In 1856 M. Struve measured the parallaxes of η Cassiopeiæ, μ Cassiopeiæ and *Capella*, while in 1859 he determined the parallax of *Vega*.

In 1858 the health of the elder Struve broke down, and in 1861 he resigned the directorship of the great observatory to his son. In 1864 Otto Struve had a very severe illness, and temporarily resigned his position to his relative, the German astronomer Winnecke.* Fortunately for science, he was soon able to again undertake the duties of director.

M. Struve's observations on nebulæ now claim our attention. For many years he attentively observed the Orion nebula. He paid attention to the stars of the trapezium, and in 1863 noted the disappearance of one of these numbered Bond 647. The star Bond 654 was also noted by him to be variable. Perhaps, however, his most remarkable observations on the nebula related to its variation in brilliance. "The observations as to the distribution and brightness of the nebulous matter do not

* Born 1835; died 1897. Discoverer of a periodic comet known by his name.

imply any change of form, but many fluctuations in the brightness of the different parts," he wrote in 1862. "The general impression which I have received from these observations is, that the central part of the nebula is found in a state of continual agitation, like the surface of the sea."

In 1868 M. Struve discovered a nebulous mass in Taurus which, D'Arrest was certain, was not previously there. It was observed until 1877, when it disappeared and was never seen again. No explanation can be given as to the nature of temporary nebulæ; they are perhaps the most enigmatical of all the celestial bodies.

In 1873 Professor Struve announced that he had discovered the long-looked-for satellite of *Procyon*, whose existence had been predicted by Bessel and Mädler from the perturbations produced by it in the motion of the bright star. The astronomer and his assistants measured its position and found it to agree with that required on the hypothetical orbit; and the star was seen and measured by other observers in Russia. Professor Newcomb, however, could see nothing of it with the 26-inch telescope of the Washington Observatory; and at last M. Struve announced that the star was merely an optical illusion. The actual satellite was discovered at the Lick Observatory in 1896.

In 1874, Professor Struve—independently of M. Flammarion—discovered the remarkable irregularities in the motion of the third component of the triple star ζ Cancri, the components of which were respectively detected by Mayer and Herschel. The close pair mutually revolve in about sixty years; and the third star appears to be moving round them. The path of the third star, however, is not by any means regular, but, in Miss Clerke's words, "is looped into a series of epicycles, in traversing which the star alternately quickens and slackens, or even altogether desists from its advance, while increasing or diminishing, by proportionate amounts, its distance from the centre of motion." Professor Struve showed that these irregularities were quite methodical. The accelerations of motion, he showed, were compensated by slow motion, while

expansions of the star's track attended accelerated motion, and *vice versa*. Professor Struve was led to the theory that these pertubations were caused by a dark body, and he offered this as a hazardous explanation, which was, fifteen years later, fully developed by Professor Seeliger, of Munich, whose work is considered in another chapter.

The 15-inch telescope of the Pulkowa Observatory had now been far surpassed by other telescopes, notably the 26-inch refractor of the Washington Observatory. M. Struve, therefore, saw that it would be well to erect a new telescope, so that the Pulkowa Observatory could retain its position as "the astronomical capital of the world," as Gould called it. In 1878, therefore, Struve arranged with the Russian government for a grant of money with which to build a giant refractor. Professor Newcomb, in his "Reminiscences of an Astronomer" remarks—"I called his attention to the ability of Alvan Clark & Sons to make at least the object-glass, the most delicate and difficult part of the instrument." After fruitless negotiations with European opticians, M. Struve visited the United States in the summer of 1879, when he was the guest of Professor Pickering at Harvard Observatory. He arranged with the Clarks for the construction of the object-glass. In 1883 he paid another visit to America to test the object-glass, and the great telescope was mounted at Pulkowa in 1884. The object-glass is 30 inches in aperture, and it was surpassed in size only by the erection of the Lick telescope four years later.

During his directorship of the Observatory, M. Struve attracted to Pulkowa a large number of astronomers, particuliarly Germans. Among these were Winnecke, his relative, the discoverer of a short-period comet; Döllen, who measured the parallax of 1830 Groombridge; C. A. F. Peters, also a searcher after stellar parallax; Hugo Gyldén, the great Finnish astronomer and mathematician; Wagner, a son-in-law of Hansen, the great mathematician; and Signor Schiaparelli, who practised at Pulkowa in 1859. In 1888 M. Bélopolsky, of Moscow, now the leading Russian astronomer, joined the observatory under the direction of Struve.

In 1890 Dr. Struve retired from the position of director of the Pulkowa Observatory, where he was suceeded by the late Professor Brédikhine. Professor Struve retired to Germany, the home of his ancestors, settling at Carlsruhe, in Baden, where he has since resided. His son promises to shed further lustre on the name of Struve. Professor Hermann Struve, now of Berlin, has devoted considerable attention to the motions of Saturn's satellites; in recognition of this he received in February 1903 the Gold Medal of the Royal Astronomical Society; and in a letter to the President of the Society, Dr. Otto Struve remarked (January 1903) that only age and infirmity prevented his undertaking a journey to England.

It would be difficult to over-estimate the services of Otto Struve to astronomy. Besides his work on Saturn's rings, on nebulæ, and on the solar motion, he is one of the five greatest double-star observers who have ever lived. His reputation is an enduring one, and his name may well be placed among the greatest astronomers of the nineteenth century.

Sir William Huggins.

AMONG the greatest of living astronomers, the name of Sir William Huggins holds a conspicuous place. We may look upon him as—independently of Secchi—the founder of stellar spectroscopy, who has made spectroscopic astronomy a profitable field of scientific research. When we consider that, half a century ago, the discoveries made by Sir William Huggins would have been deemed impossible, and that he founded an entirely new branch of the science of the heavens, it will be seen that he is worthy to rank with the great men of the past.

William Huggins was born in London, on February 7, 1824. He received his education at the City of London School, and, instead of following an ordinary university career, studied classics, mathematics, modern languages, and science, under private tutors, devoting himself especially to chemistry, electricity, and astronomy. In 1852, at the age of twenty-eight, he entered upon the study of animal and vegetable physiology, having been attracted to that science by the rapid discoveries then being made by means of the microscope.

After four years, however, he abandoned physiology for astronomy. In 1856 he purchased a house at Tulse Hill, near London, then a much more rural situation than it is at present, and there he built an observatory, and, at great expense, equipped it with astronomical instruments, one of his earliest telescopes, which he purchased from his friend, the Rev. W. R. Dawes, costing £200.

For some time Mr. Huggins observed the celestial bodies with his various telescopes. He began work on the lines then common, taking observations of transits, and making drawings of the planets. However, he soon became tired of the routine of ordinary astronomical work, and longed for new methods of observing the heavens. At this time (1859) news arrived of Kirchoff's discovery that the Fraunhofer lines in the spectrum of the Sun indicated the existence in the great luminary of the elements with which we are familiar on the Earth. "The news was to me like the coming upon a spring of water in a dry and thirsty land," Sir William Huggins wrote in June 1897 in the *Nineteenth Century*. "Here at last presented itself the very order of work for which in an indefinite way I was looking. . . . A feeling as of inspiration seized me: I felt as if I had it now in my power to lift a veil that had never before been lifted; as if a key had been put into my hands which would unlock a door which had been regarded as for ever closed to man."

It was plain, however, that unless there was a great improvement in the spectroscope, investigations on the spectra of the stars would not be practicable. Notwithstanding the brilliancy of the Sun, it was difficult to secure a perfect spectrum; for a star of the first magnitude, from which we receive only one forty thousand millionth part of the Sun's light, no instrument then in use was suitable. Mr. Huggins was therefore obliged to construct new apparatus and invent new methods of research.

In conjunction with Dr. W. A Miller, Professor of Chemistry in London, Mr. Huggins began his long career of astronomical research. He arrived at the conclusion that the exhaustive investigation of the spectrum of a single star would occupy several years. On February 19, 1863, he communicated to the Royal Society some preliminary results of his investigations, and some time later furnished details of the spectra of the two red stars, *Betelgeux* and *Aldebaran*. In the former star, he ascertained the existence of sodium, iron, calcium, magnesium, and bismuth. From the dark lines in the spectrum of

Aldebaran, he found that the elements present in *Betelgeux* were conspicuous in the leading orb of Taurus, with the addition of tellurium, antimony, and mercury. He also ascertained that hydrogen, sodium, iron and magnesium were present in the brilliant *Sirius*, and probably also in the other stars observed. These observations were almost the first made on stellar spectra. It is true that Donati in 1860 began observations on the spectra of the stars, but his studies yielded no important results, owing to the imperfection of his instruments. Secchi, the great contemporary of Huggins, aimed at a comprehensive survey of stellar spectra, and not at a searching examination of certain stars. Thus, the English astronomer had his particular department of stellar spectroscopy almost to himself. His investigations were soon to be rewarded by some brilliant discoveries.

For years the question of the constitution of the nebulæ had perplexed astronomers. The elder Herschel regarded some of these hazy clouds as gaseous, and on this he founded his nebular hypothesis of stellar evolution. This view, although emanating from so great a man, began to lose its popularity in the middle of the century. The great Rosse reflector resolved several nebulæ into stars shortly after its erection in 1845, and indeed the American astronomer Olmsted, writing about the year 1854 on the supposed resolution of the Orion nebula, declared it to be the signal for the renunciation of Herschel's nebular theory; while Sir David Brewster confidently believed that all irresolvable nebulæ were clusters of stars at vast distances, and that they would be resolved by increase of telescopic power.

On August 29, 1864, Mr. Huggins turned his spectroscope on a bright planetary nebula in the constellation Draco. In his own words, "The reader may now be able to picture to himself to some extent the feeling of excited suspense, mingled with a degree of awe, with which after a few moments of hesitation I put my eye to the spectroscope. Was I not about to look into a secret place of Creation?" To his surprise, the spectrum was one of bright lines, which proved conclusively that the nebula

was a mass of glowing gas. He found that the Great Nebula in Orion, one of the objects which Herschel believed to be irresolvable, consisted of incandescent gas, chiefly hydrogen. By 1868 Mr. Huggins had observed the spectra of seventy nebulæ, and one-third of these proved to be gaseous. He found that the Andromeda nebula displayed a continuous spectrum—in other words, that it was not a mass of gas like that in Orion. It is believed to be in a further stage of its existence than the gaseous nebulæ.

The discovery that the nebulæ were really gaseous marks an epoch in astronomy, and forms one of the most dramatic chapters in the history of astronomical science. Mr. Huggins' discovery swept away the great objection to the Nebular Hypothesis of Herschel and Laplace, and opened the way to further investigation.

On the night of May 12, 1866, a new star of great brilliancy blazed out in the constellation Corona Borealis, and was detected near midnight by the late Mr. Birmingham, an Irish astronomer. Four hours earlier, the great German observer, Schmidt, affirmed it was not visible. On the night of May 18, when the star had faded considerably, Mr. Huggins observed it with the spectroscope and ascertained the existence of hydrogen. In the words of Sir Robert Ball—"I well remember going with Lord Rosse, in 1866, to pay my first visit to Dr. Huggins' observatory at Tulse Hill. One of the objects he showed us was the spectrum of this star . . . The feature which made the spectrum of the new star essentially different from that of any other star which had been previously observed, was the presence of certain bright lines, superposed on a spectrum with dark lines of one of the ordinary types. The position of certain of these lines showed that one of the luminous gases must be hydrogen. It is impossible to dissociate the spectroscopic evidence from the circumstances known in connection with this star. The spectroscope showed that there must have been something which we may describe as a conflagration of hydrogen on a stupendous scale."

In 1864 Mr. Huggins examined the planet Mars spectros-

copically in the hope of determining the nature of its atmosphere, but without satisfactory results. At the opposition of 1867 he again observed the planet, attaching a spectroscope to his 8-inch refractor. The spectrum was crossed, at the red part, by dark lines similar to those which appear in the solar spectrum when the Sun is near the horizon. These solar lines are caused by the aqueous vapour in our atmosphere. Mr. Huggins, observing these lines in Mars, believed them to prove the existence of water on the planet. To make the discovery certain—in fact, to prove that the lines did not belong to our own atmosphere,—he examined the Moon, which was nearer the horizon than Mars. The lines were not visible in the lunar spectrum, showing that they belonged to that of Mars. This proved conclusively the existence of aqueous vapour in the planet's atmosphere. Dr. Vogel confirmed this some years later.

Perhaps the greatest of Mr. Huggins' numerous achievements was his discovery of the method of observing the motions of stars in the line of sight. As far back as 1842, Christian Doppler, Professor of Mathematics at Prague, had expressed the view that the colour of a luminous body must be changed by its motion of approach or recession. It was obvious to Doppler that if the body was approaching, a larger number of light waves must be entering the eye of the observer than if it were retreating. Miss Clerke thus illustrates Doppler's principle—"Suppose shots to be fired at a target at fixed intervals of time. If the marksman advances say twenty paces between each discharge of his rifle, it is evident that the shots will fall faster on the target than if he stood still; if, on the contrary, he retires by the same amount, they will strike at correspondingly longer intervals."

It occurred to Mr. Huggins that by applying Doppler's principle to the stars, he could determine, by the shifting of the lines in their spectra—not by any change in their colour—their motions in the line of sight, which cannot be measured telescopically. Mr. Huggins communicated to the Royal Society his first results in this branch of astronomy on April

23, 1868. In the case of *Sirius*, the displacement of the Fraunhofer line, marked F, was believed to show that this brilliant star was moving from the Solar System at the rate of twenty-nine miles a second. Some time later, he announced that *Betelgeux*, *Rigel*, *Castor*, and *Regulus* were retreating, as were also five of the seven stars of the Plough, a confirmation of Proctor's theory of star drift; *Arcturus*, *Pollux*, *Vega*, and *Deneb* in Cygnus, on the other hand, gave signs of approach. The astronomer was not successful, however, in measuring the radial motions of the nebulæ. His observations inaugurated a series of wonderful discoveries by means of Doppler's principle, which in the hands of Dr. Vogel, Professor Pickering, Professor Campbell, Dr. Bélopolsky, and the late Professor Keeler, has yielded marvellous results.

Dr. Huggins also gave much attention to solar astronomy. After the discovery by M. Janssen and Sir Norman Lockyer of the method of observing the spectrum of the red flames of the Sun without eclipses, Dr. Huggins, on February 13, 1869, inaugurated the study of the forms of the red flames themselves in daylight. "It was an immense gain," says Miss Clerke, "to find their rays strong enough to bear so much of dilution with ordinary light as was involved in opening the spectroscopic shutter wide enough to exhibit the tree-like, or horn-like, or flame-shaped bodies rising over the Sun's disc in their undivided proportions." It is well known that the continuous spectrum of sunlight is weakened by increase of dispersive power, and therefore the spectrum of the prominences, composed of bright lines, is observable. By widening the slit, Dr. Huggins observed the forms of the prominences themselves. This "open-slit" method was also devised by the late Dr. Zöllner of Leipzig.

Mr. Huggins' great discoveries were rewarded in 1866 by the presentation to him of the Royal Society's Royal Medal. In 1867, also, he received—along with Dr. Miller—the Gold Medal of the Royal Astronomical Society, and a second medal was awarded to him in 1885. In 1869 he was Rede Lecturer at Cambridge, and the following year received the degree of

LL.D. from the University there, and some time later the degrees D.C.L. from Oxford, and LL.D. from Edinburgh. He received the Lalande Prize ftom the French Academy of Sciences in 1872, and was elected to many of the scientific societies of the Continent; he received from the University of Leyden the degree of Doctor of Physics and Mathematics, and by the last Emperor of Brazil was created a Commander of the Rose. In 1876 Dr. Huggins became President of the Royal Astronomical Society.

In cometary astronomy, Dr. Huggins was a pioneer, although the first observation of the spectrum of a comet had been made by Donati. His observations on the comet of 1868 showed that the chief source of its light was carbon. It was found that the light of comets is partly inherent and partly reflected. Dr. Huggins also ascertained the existence in comets of hydrogen and nitrogen.

As early as 1863, Dr. Huggins had attempted to photograph the spectra of the stars, and although he obtained prints of *Sirius* and *Capella*, no lines were visible in them. In 1876 he made another attempt. Although more successful, he was not yet satisfied, and worked at the subject for three years longer. At last, in December 1879, he forwarded to the Royal Society results answering satisfactorily to his expectations. This must be placed among his greatest achievements. The extraordinary care necessary for the exposure of the plates may be estimated from the fact, that the image of the star had to be kept exactly projected for nearly an hour by continual minute adjustments * on a slit 1-350th part of an inch in width.

Dr. Huggins, in 1882, came to the conclusion that it would be possible to photograph the corona of the Sun without a total eclipse. So faint is the coronal light that it cannot be seen owing to the glare of the orb of day. Dr. Huggins, however, by using chloride of silver—a substance peculiarly sensitive to coronal light—hoped that he would be successful.

* These adjustments are necessary in delicate celestial photography, owing to air tremors and minute irregularities in the clock-work motion of the telescope.

Indeed, by September 28, 1882, he had obtained some photographs on which the filmy corona was visible. But the results of the eruption of Krakatoa in Ausgust 1883 proved fatal to coronal photography, owing to the quantities of fine dust flung into the air from the volcano. The forms of the corona, therefore, ceased to appear on the Tulse Hill plates.

Dr. Huggins' views on stellar evolution are similar to those of Dr. Pickering and Dr. Vogel. In his presidential address to the British Association in 1891, he attributed the inconspicuousness of the metallic lines in the spectra of white stars to the high temperature of the vapours which produce them. He places the brighter stars, in order of evolution, *Bellatrix*, *Rigel*, *Deneb*, *Regulus*, *Vega*, *Sirius*, *Castor*, *Altair*, *Procyon*, γ Cygni, *Capella*, *Arcturus* and *Betelgeux*. He is of opinion that the solar type contains the hottest stars.

Dr. Huggins has long devoted attention to the Orion nebula. He early ascribed the "chief nebular line" to nitrogen, but found this view to be untenable; in 1890 he was able to prove that the line does not coincide with the magnesium fluting, as Professor Lockyer supposed. He secured an exquisite photograph of the spectrum of the Orion nebula in 1888.

The new star which appeared in Auriga in the end of 1891 was carefully examined by Dr. and Mrs. Huggins at Tulse Hill. From a spectroscopic study, Dr. Huggins propounded a theory of the new star which is thus described by Frost—"The case is that of the casual near approach of two bodies previously possessing considerable velocities in space—such a near approach being far less improbable than an actual or partial collision. Enormous disturbances of a tidal nature would inevitably follow such approach, and produce sufficiently great changes of pressure in the interior of the bodies to cause tremendous eruptions from within, similar in kind to solar outbursts, but immensely greater." Dr. Huggins opposed the view that the star was transformed into a planetary nebula, and his opinion was shared by Dr. Vogel.

That England's greatest living astronomer considers that we are still at the beginning of our knowledge of the Universe is

made evident from his remark at his Cardiff address in 1891—"Since Newton's day, our knowledge of the phenomena of Nature has wonderfully increased; but man asks, perhaps more earnestly now than then, what is the ultimate reality behind the reach of the preceptions? Are they only the pebbles of the beach with which we have been playing? Does not the ocean of ultimate reality and truth lie beyond?"

From the Institute of France, Dr. Huggins received the Valz Prize in 1883, and the Janssen Gold Medal in 1888. He presided over the meeting of the British Association at Cardiff in 1891. He received the degree of LL.D. from Dublin in 1886, and from St. Andrews in 1893, and the Royal Society conferred upon him the Copley Medal. In 1897, on the occasion of Queen Victoria's Diamond Jubilee, the illustrious astronomer was created a Knight Commander of the Bath. The results of his work were published in 1899, in his great work "An Atlas of Representative Stellar Spectra," the joint work of Sir William and Lady Huggins, which has been described as "the greatest astronomical book of the present time—one of the greatest astronomical books of all time."

In 1900 Sir William Huggins became President of the Royal Society, and still retains that position. He has long served the Astronomical Society as President, Vice-President, Member of the Council and, latterly, Foreign Secretary. In 1901 he received the Henry Draper Gold Medal from the National Academy of Sciences in Washington. Sir William is an Honorary Member of the Astronomical and Physical Society of Toronto. In June 1902, on the occasion of the King's Coronation, Sir William Huggins was one of the twelve men selected to be the first members of the New Order of Merit.

Notwithstanding Sir William Huggins' advanced age, he is still working at astronomy. He has recently been employed in the study of the wonderful new element, Radium. Professor Kayser of Bonn says of him, that he "is distinguished by the extraordinary accuracy of all his publications. He has always been very cautious in drawing conclusions from observations; with an enthusiatic heart he has combined a cool head. He

has scarcely ever been forced to retract or modify a statement, and, therefore, his views are universally accepted and his authority remains unrivalled."

In closing this review of the life and work of Sir William Huggins, it would be unjust not to mention his sole assistant, Lady Huggins, who, it may be observed, has found time for original investigations in spectroscopic astronomy. Lady Huggins, who was born in Ireland, became early devoted to astronomy, and, when a child, studied the stars at night by means of star maps and a dark lantern, and the sun during the day with an apparatus which she herself constructed. In 1875 she married Dr. Huggins, and since then all the publications at Tulse Hill have been signed by both Sir William and Lady Huggins. She has been to her husband as Caroline Herschel was to her illustrious brother.

It will be seen from the honours which have been bestowed upon Sir William Huggins from all quarters of the globe that he is held in universal esteem, and is considered to be not only one of the greatest living astronomers, but one of the greatest living men of science. He is now reaping the harvest of a distinguished scientific career—a life spent in noble devotion to the grandest of the sciences.

Pierre Jules César Janssen.

One of the greatest French astronomers of modern times is the venerable Dr. Janssen, the founder of French astrophysics, who must rank with Huggins and Secchi as one of the founders of celestial spectroscopy. The discoveries of Dr. Janssen, it has been remarked by one of his countrymen, mark "an epoch in the history of our knowledge of the Universe."

Pierre Jules César Janssen was born in Paris on February 22, 1824. His father was Antoine César Janssen, an eminent musician, and his grandfather the French architect Lemoyne. He received a good education, latterly at the Faculty of Paris. After the completion of his education, he studied chemistry and physics, and was for some time a teacher of mathematics and architecture. In 1857 he visited Peru to determine the position of the magnetic equator; a serious illness, however, compelled him to return to France. Three years later he became Doctor of Physical Science; and in 1865 was appointed Professor of General Physics at the School of Architecture, a post which he retained for six years.

About this time, M. Janssen was sent by the French Academy of Sciences to study spectroscopic astronomy in the beautiful climate of Italy, and in 1864 he commenced investigations at Nyon, on the lake of Geneva, where he studied the solar spectrum and the absorption lines caused by the Earth's atmosphere. In 1867 he made spectroscopic observations from the summit of Etna and studied especially the spectra of

Pierre Jules César Janssen.

the planets. In the spectrum of Saturn he recognised unmistakable traces of aqueous vapour.

M. Janssen's name is inseparably associated with the observation of solar eclipses, for which purpose he has travelled over the world. His eclipse observations have been of the utmost value and have yielded important discoveries. In 1867 he observed an annular eclipse of the Sun, in Italy, but his greatest observation was made in 1868, when he discovered, independently of Sir Norman Lockyer, the spectroscopic method of observing the solar prominences in full daylight.

To observe the "red flames" of the Sun, or solar prominences, during the total solar eclipse of August 18, 1868, M. Janssen was stationed at Guntoor, in India. The morning of the eclipse was not perfectly clear, and the atmospheric conditions not particularly good, but M. Janssen persisted in his observations and observed the spectrum of the solar prominences, which was composed of bright lines, proving that these prominences were masses of glowing gas. During the progress of the eclipse, M. Janssen was specially struck by the brilliancy of the bright lines from the prominences. The idea accordingly struck him that the spectrum of the prominences might be observed even when the Sun is not eclipsed. As Proctor remarks in his work on "The Sun": "The light of the prominences, when dispersed by the spectroscope, forms a few lines; that of the illuminated terrestrial atmosphere is spread out into the rainbow-tinted solar spectrum. Therefore if we only use adequate dispersive power, we can cause the prominence lines to show conspicuously on the background of dispersed atmospheric light."

During the progress of the eclipse, as we have remarked, the idea of observing the prominences in daylight occurred to M. Janssen, but after it was over, clouds gathered, which prevented the observations. But at ten o'clock on the following morning, August 19, 1868, M. Janssen applied his spectroscope to the Sun and observed the spectra of the prominences during the entire day. "I have experienced to-day a continuous eclipse," he remarked. The spectroscope revealed to him the

disruption of a protuberance which had been at the time of the eclipse at least 89,000 miles in height, but which was the following day completely shattered. His observations, continued in India, showed that bright lines were to be seen all round the limb of the Sun, confirming the existence of the solar envelope, the "sierra," or "chromosphere," which had already been affirmed by Secchi, Le Verrier, Grant and Von Littrow.

M. Janssen sent the report of his discovery to the French Academy of Sciences on September 19, but the news was nearly two months in arriving in Europe. Professor Lockyer had, in October 1868, made, unaware of M. Janssen's result, an analagous discovery. Only a short time before the news from M. Janssen reached the French Academy, Professor Lockyer had sent a similar communication. To commemorate this discovery, a medal was struck by the French Government in 1872. The new method of studying the prominences was followed up by the discoverers themselves, by Huggins in London, Zöllner and Vogel in Leipzig, Spörer at Anclam, Pomerania; Secchi and Respighi in Rome; Tacchini at Palermo; and Young at Dartmouth, New Hampshire.

The advantage which astronomy gained through M. Janssen's discovery can scarcely be over-estimated. Previously, astronomers could only observe the solar prominences for a few seconds at a time, during total eclipses. M. Janssen showed that, if sufficient dispersive power were used, they could be observed at any time. The result is that we have now a continuous record of solar prominences since 1868.

M. Janssen's successful observations in 1868, showed astronomers that, so far as the solar prominences were concerned, eclipses could be dispensed with, but even at the present day, no method has been devised by means of which the corona can be observed in full daylight. Accordingly astronomers began to prepare for the total eclipse of December 22, 1870. At this time M. Janssen was in Paris, which was besieged by the Prussian army, but so determined was he to observe the eclipse—visible in Italy—that he escaped from the besieged city in a balloon, carrying with him parts of a reflecting

telescope specially constructed for observations on the corona, but at Oran, clouds completely obscured his view of the eclipse, while Professor Lockyer, in Sicily, was almost equally disappointed. In 1871, M. Janssen again visited India for the purpose of observing the eclipse which took place on December 12 of that year. He observed the corona with the spectroscope and ascertained the existence in its spectrum of some of the dark Fraunhofer lines, the most conspicuous of which was the D line, characteristic of sodium. His observations also showed that hydrogen existed outside the region of the protuberances. Consequently it forms part of the corona. In 1874, M. Janssen observed the transit of Venus at Nagasaki, and in the China seas he had a narrow escape from a typhoon. The second transit, in 1882, was also observed by the distinguished French astronomer, who observed the planet spectroscopically, and was surprised at the relative scarcity of indications of aqueous vapour.

In 1875 it was decided to found an astrophysical observatory in connection with the great institution at Paris. The following year it was erected at Meudon, in the department of Seine-et-Oise, and M. Janssen was appointed director, a position which he still retains. Since his appointment, he has devoted much time to the study of the Sun's surface by means of direct photographs.

A total eclipse of the Sun was visible in the Pacific Ocean, May 6, 1883, with the unusual length of five minutes. The only land from which it was visible, however, was Caroline Island, a coral rock, seven and a half miles in length and one and a half wide. M. Janssen, however, was ready to bear all the inconveniences of the voyage for the sake of his favourite science. He was chief of the expedition sent out by the French Academy of Sciences, and was accompanied by M. Trouvelot from Meudon, and by M. Palisa from Vienna, and Professor Tacchini from Rome. "Seldom," writes Miss Clerke, "has a more striking proof been given of the vividness of human curiosity as to the condition of the worlds outside our own, than in the assemblage of a group of distinguished men from the chief centres of civilisation, on a barren ridge,

isolated in a vast and tempestuous ocean, at a distance, in many cases, of 11,000 miles, and upwards, from the ordinary scene of their labours." Fortunately the sky was clear on the day of the eclipse and valuable observations were made. M. Janssen again observed the spectrum of the corona, and fully confirmed the existence of dark Fraunhofer lines of reflected sunlight.

M. Janssen's observations of the Sun at the Meudon Astrophysical Observatory have been of the utmost importance. He has since 1876 obtained many direct photographs of the solar surface, some of which have been obtained with an exposure of only $\frac{1}{100,000}$th of a second in length. These photographs have revealed a remarkable phenomenon, known as the "réseau photosphérique," the distribution over the solar disc of blurred patches of light, which are probably inherent in the Sun itself, if we accept the conclusion of M. Janssen. M. Janssen has expressed the opinion that the cloudlets of the photosphere change their shape in a period coincident with that of the sun spots.

Dr. Janssen's photographs of the Sun have been preserved in his great Solar Atlas, presented by him in January 1904 to many of the learned societies of Europe. This magnificent atlas comprises six thousand photographic registrations of the solar surface, from the foundation of the Meudon Observatory in 1876 down to 1903.

In 1884 M. Janssen attended the Prime Meridian Conference at Washington. In 1886 and subsequent years he took part in the Congress at Paris for the International Chart of the Heavens. He has presided over the Société Astronomique de France. He published, since 1898, a volume of his principal lectures to the Academy of Sciences, of which he was in 1873 elected a member, and funeral orations delivered at the burial of distinguished French *savants*. M. Janssen, when presiding over the Academy, in 1887 and 1888, founded the Janssen prize for astrophysics, an honour conferred on Sir William Huggins, M. Bélopolsky, Professor Tacchini, Professor Young, and other eminent astronomers.

About this time the idea occurred to the illustrious French astronomer that it would be desirable to found a Meteorological Observatory on Mont Blanc.* In 1890 he made an ascent of Mont Blanc, and came to the conclusion that it was possible to found the proposed Observatory, the erection of which was agreed upon. It was hoped that the snow cap on the summit of Mont Blanc could be pierced and the Observatory erected, but M. Janssen considered that it might be possible to erect the Observatory on the ice itself, which was proved to be quite strong enough to bear the weight of the building. By the end of 1893 the Observatory was almost completed.

In September 1893, M. Janssen again ascended Mont Blanc for the purpose of determining the absence or presence of oxygen in the Sun. The supposed bands of oxygen, announced in 1879, were thought by him to owe their presence to the oxygen in the terrestrial atmosphere, as well as to the presence of the element in the Sun itself. In 1890 he was enabled to prove that on Mont Blanc the oxygen bands were much enfeebled, leaving no doubt as to their terrestrial origin. His ascent of Mont Blanc in 1893 gave even more decisive results. His observations were made with a Rowland grating spectroscope, on the group of lines in the solar spectrum known as B. This group consists of double lines, of which thirteen or fourteen are visible at the sea level. At Chamounix (3400 feet), in the Alps, M. Janssen could scarcely see the thirteenth double line, at the Grands Mulets (10,000 feet), he could only see to the tenth or eleventh pair, and on the summit of Mont Blanc (15,731 feet)—where the absorption is reduced by about one-half—he was unable to observe beyond the eighth pair of lines, proving that the lines were due to the oxygen absorption in the terrestrial atmosphere, and did not signify its presence in the orb of day. Recent observations, however, seem to show that oxygen does exist in the Sun, although the lines observed by M. Janssen undoubtedly owe

* An interesting description of the foundation of the Observatory is given in Mr. Gore's "Worlds of Space."

their origin to the Earth's atmosphere, a conclusion confirmed by Dr Dunér some time later.

A number of honours have been conferred on Dr. Janssen for his services to astronomy. In addition to numerous lesser honours, he is a Foreign Member of the Royal Society of London, and of the Academies of Rome, Brussels, and St. Petersburg. He is a Knight of the Legion of Honour, of the Brazilian Order of the Rose, of the Mérite Scientifique de Portugal.

By his unwearied devotion to the science of astronomy Dr. Janssen has earned for himself a position second to none among the French observers of the nineteenth century. To him belongs the credit of having been the pioneer of spectroscopic astronomy in France. We owe to his perseverence in spectroscopic observations of the Sun, the discovery that the solar prominences can be observed in daylight, a discovery which opened up an entirely new field of research; his observations of the spectrum of the corona have shown that it shines partly by reflected sunlight; while his numerous observations of total eclipses have been fruitful of new discoveries and ideas. The world of science owes much to the laborious researches of the great French astronomer.

Asaph Hall.

(Photo. by Chickering, Boston.)

Asaph Hall.

The subject of this chapter, Professor Asaph Hall, the discoverer of the satellites of Mars, occupies a prominent position in the astronomy of the United States. He is the oldest living American astronomer of note; and his discoveries have been both important and striking. His life, like that of so many other present-day astronomers, is a brilliant example of perseverance under difficulties. His early history, as Lord Crawford remarked in 1879, when presenting to him the Gold Medal of the Royal Astronomical Society, "affords a bright example of what perseverance and determination may effect in overcoming even the most adverse circumstances."

Asaph Hall was born at Goshen, Connecticut, on October 15, 1829. His father, Asaph Hall, was the son of a revolutionary officer, one of the first settlers in Goshen. The family was at one time wealthy, but became poor through commercial failure. Asaph Hall received his education at the school of his native village, and from his father, who, however, died when the future scientist was only thirteen years old, leaving the family in debt. After several unsuccessful efforts to retain his father's farm, Asaph Hall apprenticed himself to a carpenter, but devoted his spare time to the study of mathematics. Intending to become an architect, he studied mathematics at Norfolk, Connecticut, after which he studied at Central College, McGrawville, New York. After spending several years in Wisconsin, he entered the University of Michigan in 1856, and studied astronomy under Dr. Brünnow, the German

astronomer, afterwards Astronomer Royal of Ireland. Thence he proceeded to Harvard and was appointed assistant to Bond in the Observatory, with a salary of three dollars a week. He retained his position at Harvard until August 1862, when he was appointed "aide" in the United States Naval Observatory at Washington, and the following year he became Professor of Mathematics in the U. S. Navy. In the same year he made an elaborate investigation of the solar parallax from observations of Mars.

During the first few years of his service at the Observatory, Mr. Hall made a number of important investigations. He contributed to the *Astronomische Nachrichten*, the great German periodical, a remarkable paper on the "Positions of the Fundamental Stars." In 1868 he observed an occultation of *Aldebaran*, which was not predicted in the English or American *Nautical Almanacs*, and which took place when the Moon was invisible owing to close proximity to the Sun. Professor Hall commenced in 1864, and completed in 1870, a catalogue of 151 stars in the cluster *Praesepe*, in Cancer, from observations with the Washington Equatorial. In the latter year he published a highly technical paper on the perturbations of the planets. In 1871 he contributed to *Silliman's Journal* a paper on the probable existence of a resisting medium in space. He came to the conclusion that the movements of the comets of Faye and Winnecke gave no indications of the existence of such a medium.

In 1873, the great 26-inch refractor was mounted at Washington. Professor Newcomb, in his "Reminisences of an Astronomer," tells us that for two years he made observations with the great telescope, and in 1875 he was succeeded by Professor Hall, who at once began his important investigations on the celestial bodies. The most memorable discoveries were those of the satellites of Mars, and that of a white spot on Saturn. Alhough the instrument is one of the finest, and its situation favourable, yet, as Sir Robert Ball well says, "it would be absurd to attribute his success either to the locality of his workshop or to the perfection of his tools. A man's genius

is best shown by the right use which he makes of his opportunities."

From 1875 to 1889, Professor Hall, with the great instrument, paid special attention to the planet Saturn. He found that the planet's globe exhibited very few changes. On December 7, 1876, however, he discovered a white equatorial spot on the planet, which he watched attentively until January 2, 1877. From observations of the spot, he found that the rotation of the individual spot, and probably of Saturn, was performed in 10 hours, 14 minutes, 24 seconds. This was confirmatory of the observations of Herschel, who, in 1794, found a rotation period of 10 hours 16 minutes. Mr. Stanley Williams, an English observer, confirmed, in 1891 and the next few years, the estimate of Professor Hall; but Professor Barnard's and Mr. Denning's observations of another spot, in 1903, indicate a longer rotation period.

In 1877 Professor Hall made his greatest discovery, that of the satellites of Mars. Before describing his discovery in detail, however, reference should be made to the efforts of earlier astronomers to find a Martian satellite. Kepler, almost three hundred years ago, predicted the existence of two satellites of Mars; while they figured in the romances of Voltaire and Dean Swift. Mädler, in 1830, made a thorough search for a satellite of Mars with his 3¾-inch telescope, and satisfied himself that no satellite existed with a diameter greater than twenty miles. In 1864, D'Arrest, the German astronomer, made another search, but was also unsuccessful. Accordingly the red planet was referred to by Tennyson as "the moonless Mars."

The opposition of Mars in 1877 will be long memorable for three great contributions to astronomy, Signor Schiaparelli's detection of the canals of Mars, Sir David Gill's observations of the planet, which led to an exact determination of the solar parallax, and Professor Hall's discovery of the satellites. The failure of so many other astronomers to discover the satellites almost deterred Professor Hall from making a fresh search, and he was not hopeful of success. However, he commenced his

search early in August, 1877. At first he observed all the faint objects in the vicinity of the planet, but demonstrated that they were nothing but fixed stars. Accordingly, on August 10, Professor Hall began to "examine the region close to the planet, and within the glare of light which surrounded it." So brilliant indeed was the planet, that the search would have been rendered useless had not the astronomer kept the disc just outside the field of view. On the night of August 11, Professor Hall observed a faint object which he suspected to be a satellite, but he had not finished his observation when a fog from the River Potomac stopped his work for the evening. "Professor Hall," says Professor Newcomb, his colleague at the Observatory, "confidentially showed me his first observations of an object near Mars, and asked me what I thought of them. I remarked, 'Why, that looks very much like a satellite.' Yet he seemed very incredulous on the subject, so incredulous that I feared he might make no further attempt to see the object. I afterwards learned, however, that this was entirely a misapprehension on my part."

Professor Newcomb having demonstrated that the object was not an asteroid, he suggested to Professor Hall that the satellite would not again be observed until after midnight on August 16, bad weather having prevailed for five days. On the same night, Professor Hall confirmed his previous observation, and discovered a second satellite still closer to Mars. The movements of this satellite were very perplexing to Professor Hall, who came to the conclusion that there must be three or four satellites. He soon demonstrated, however, that the inner satellite completed three revolutions while Mars performed one rotation on its axis. These satellites were named by Professor Hall *Deimos* and *Phobos*.

Professor Newcomb made the first approximate determination of the orbits of the satellites from the earlier observations. But the work was soon taken up by Professor Hall himself. He determined the times of revolution, and showed that *Phobos* revolved round Mars in 7 hours, 39 minutes, 14 seconds; and *Deimos*, in 30 hours, 17 minutes and 54 seconds.

He gave the elements of the satellites in a volume published in 1878. The satellites were photometrically measured soon after their discovery, by Professor Pickering, who estimated their diameters at six and seven miles; but Mr. Lowell's more recent observations show them to be considerably larger. These satellites, on account of their small size and rapid motion, are perhaps the most curious objects in the Solar System. As *Phobos* revolves round Mars in a much shorter period than the planet requires to rotate on its axis, the satellite must, to an observer on the planet, appear to rise in the west and set in the east, passing across the heavens in five and a half hours. As *Deimos* takes thirty hours to move round Mars, it will appear to rise in the east and remain above the horizon for more than two days at a time. The extremely rapid motion of *Phobos* was for long an obstacle to the acceptance of Laplace's Nebular Theory, but it can be explained by Professor Darwin's theory of tidal friction. "Such," says Lord Crawford and Balcarres, "is the history of a great astronomical discovery; and it is satisfactory to think that the United States Government has received a reward already* for the enlightened munificence displayed in placing so magnificent an instrument in the hands of one so capable of using it."

The discovery of the satellites of Mars rendered the name of Asaph Hall famous throughout the astronomical world. Honours now began to pour in on the fortunate discoverer. In 1878 he received the Lalande Prize of the Paris Academy of Sciences, and in 1879 the Gold Medal of the Royal Astronomical Society. Yale College conferred on Professor Hall the degree of L.L.D. in 1879, and Harvard in 1886.

From the year 1874 until 1891, Professor Hall made an important series of observations on double stars. From 1879 until 1891 he studied especially the famous double star 61 Cygni, the nearest star in the Northern Hemisphere. The observations, which were made with the 26-inch equatorial, favoured the physical connection of the components; but this view is not shared by Professor Burnham. While employed at

* 1879.

Washington, Dr. Hall undertook several important investigations of stellar parallax. He confirmed in 1886 Brünnow's parallax of *Vega*, while he determined the parallax of 6 Cygni, and re-measured that of 61 Cygni. The triple star, 40 Eridani was found by Dr. Hall to have a parallax of about $\frac{1}{5}$th of a second of arc.

In 1884 Dr. Hall published the results of some interesting observations on the satellites of Saturn. He found that the five inner satellites, *Mimas*, *Enceladus*, *Tethys*, *Dione* and *Rhea*, move in the plane of the ring, and, in apparently circular orbits. *Hyperion*, the seventh satellite was found to move in the same plane as *Titan*, the sixth. Dr. Hall, however, found the orbits of *Titan* and *Hyperion* to be elliptical, and, owing to this, the satellites will sometimes approach each other very closely.

In 1885, a new star of the sixth magnitude blazed out in the heart of the Andromeda Nebula, which was attentively observed by Professor Hall, with a view to measuring its parallax. A series of observations, however, failed to reveal any measurable displacement, confirming the idea of the great distance of temporary stars. Professor Hall's failure to measure the parallax of *Nova* Andromedæ also gave the death-blow to the view expressed by the late Dr. Common, that the Andromeda nebula is comparatively near the Solar System; for, in all probability, the star was situated *in* the nebula and not in front of it. Supposing, however, that the star was seen projected on the nebula, still the nebula must be more remote than the star. Professor Hall's measures, therefore, set at rest the question of the possible proximity of the nebula; so vast indeed is this great nebula that light probably takes several years to pass across its diameter.

On October 15, 1891, Professor Hall, having reached the age of sixty-two, retired from the Government service. During his twenty-nine years of service he directed eclipse expeditions to Bering Straits in 1869; to Sicily in 1870; and to Colorado in 1878. He observed the transit of Venus at Vladivostock in 1874, and at San Antonio, Texas, in 1882. In 1896 he was elected to one of the Professorships of Astronomy at Harvard.

Since 1875 he has been a member of the National Academy of Sciences, and was until 1903 its Vice-President. His son, Asaph, is also a distinguished astronomer, and occupies the chair of astronomy in the University of Michigan. Professor Hall now resides at his birthplace, Goshen, Connecticut, where he pursues his astronomical researches.

Notwithstanding the fact that Professor Hall's greatest discoveries have been made in observational astronomy—notwithstanding that his popular fame rests on his discovery of the satellites of Mars,—still he is perhaps even more distinguished in mathematical astronomy. Like his former colleague, Professor Simon Newcomb, whose life and work is discussed in another chapter, Professor Hall is a distinguished mathematician of whom the United States has every reason to be proud. In his work are combined two qualities rarely found together—that of the keen, patient observer and the acute mathematical reasoner.

Charles Augustus Young.

Among the distinguished astronomers of the United States a high place must be accorded to by Professor C. A. Young of Princeton, New Jersey. By his unwearied labours he has become one of the chief authorities on solar astronomy, in which branch of astronomical science he is one of the most illustrious investigators. The life and work of Professor Young is an example of untiring exertion and patient labour for the cause of astronomical science.

Charles Augustus Young was born at Hanover, New Hampshire, on December 15, 1834. His father was Professor of Natural Philosophy in Dartmouth College, and, after preparatory education in the private schools, the future astronomer in 1849 entered Dartmouth College, where he graduated in 1853. In the same year he accompanied his father on a visit to Europe. He was undermaster in Classics in Phillips' Andover Academy, from 1854 to 1856, and at the same time took the course in the Theological Seminary at Andover. In 1857 he became Professor of Mathematics and Natural Philosophy in Western Reserve College at Hudson, Ohio. His attention was now turned to astronomy, and he acted during three summer vacations as astronomical assistant on the Survey of the North and North-West Lakes. In the latter part of 1862, during the Civil War, he served for four months as captain of a company of Ohio Volunteer Infantry, mostly composed of students. In 1866 he was appointed Professor of Natural Philosophy and Astronomy at Dartmouth College.

Charles Augustus Young.

At this time the spectroscope had come into prominence as a valuable aid to astronomical research. Professor Young was a member of the expedition sent to observe the total solar eclipse of August 1869. He then applied the spectroscope to the corona, and noticed a green line, which he identified as 1474 of Kirchoff's scale. This identification, however, was proved on later investigation to be incorrect. As Professor Young recently remarked in a letter to the present writer, "The corona line is slightly higher up in the spectrum (wave-length 5,304 instead of 5,316), and has no coincident dark line in the spectrum: 1474 is exclusively in the Chromosphere, not in the Corona."

In 1870 Professor Young made, perhaps, his most striking discovery, that of the so-called "reversing layer" of the Sun. He points out in his work "General Astronomy" that, as the dark lines in the spectrum are caused by the passage of light,—from the minute solid and liquid particles which make the clouds of the photosphere,—through vapours containing just the elements which are recognised in the spectrum, the gaseous envelope, which forms the dark lines by its absorption, should by itself show a spectrum of bright lines. As he remarks, it is only during a total solar eclipse that this observation can be made, and in 1869 he attempted to make it, but failed.

During the eclipse of December 22, 1870, Professor Young was stationed at Tenez de Frontena, Spain, as a member of Professor Winlock's party. Properly adjusting his spectroscope he watched carefully. As the solar crescent grew apparently thinner before the disc of the Moon "the dark lines of the spectrum," he says, "and the spectrum itself, gradually faded away, until all at once, as suddenly as a bursting rocket shoots out its stars, the whole field of view was filled with bright lines, more numerous than one could count. The phenomenon was so sudden, so unexpected, and so wonderfully beautiful as to force an involuntary exclamation." The phenomenon was observed for two seconds, and the impression was left on Professor Young that a bright line had taken the place of every dark one in the solar spectrum, the spectrum

being completely reversed. Hence the name which was given to the hypothetical envelope—"the reversing layer." For long the existence of the reversing layer was disputed by numerous astronomers, among them Sir Norman Lockyer. In 1896 photographs taken during the solar eclipse of that year finally demonstrated the existence of the "flash spectrum" as seen by Professor Young, who, from the photograph, identified the majority of the lines as simply reversals of the Fraunhofer lines, while about 25 are much more extensive and conspicuous than the others, and in his opinion "are images of the chromosphere and prominences."

In 1871 Professor Young offered his explanation of the spectrum of the solar corona, an explanation which, Dr. Scheiner remarks, "seems to hold perfectly true to-day." He remarked, in that year, that the spectrum of the corona is probably composed of four superposed elements. First, there is the continuous spectrum, undistinguished by either bright or dark lines, due, probably, to incandescent dust or solid and liquid particles near the Sun. Secondly, there is the truly gaseous spectrum, with a more or less bright continuous background, marked with several bright lines, including the green corona line and several due to hydrogen. "As far as the spectroscopic evidence goes, this gas may be simply the vapour of the meteoric dust, liberated by the heat of the Sun. The circumstances indicate, however, that the gases are of a more permanent character, being a true solar atmosphere in which, and through which, the meteoric particles move as foreign bodies." Thirdly, there is the continuous spectrum, distinguished by dark Fraunhofer lines, first observed by M. Janssen, caused by the reflection of the light of the photosphere from the meteoric dust forming the corona; while, fourthly, there is the light reflected from the particles in the Earth's atmosphere. This is a mixture of the three already named, with the addition of chromospheric light. There is no doubt, however, that the Earth's atmosphere has little to do with the phenomenon of the corona.

Professor Young early availed himself of the new method *

* See chapters on Huggins, Janssen, Lockyer.

of observing the solar prominences devised by Janssen and Lockyer, and so actively promoted by these observers, as well as Huggins, Zöllner, Secchi, Respighi, and Tacchini. Professor Young was one of the first American astronomers to observe the prominences. "These solar clouds," he says, "are the most fascinating objects to watch on account of the beauty of their forms and the rapidity of their changes." On September 7, 1871, he witnessed what Proctor calls "the most remarkable outburst on the Sun ever yet witnessed by man." At noon, he was examining a prominence by means of the spectroscopic method. "It had remained unchanged since noon of the day previously—a long, low, quiet-looking cloud, not very dense or brilliant, or in any way remarkable except for its size." At 12.30, the Professor was for a few minutes called away. Half-an-hour later, on returning to the spectroscope, he was amazed to find that the prominence had been shattered to pieces. In place of the quiet cloud the solar atmosphere was, to use his expression, "filled with flying *debris*." Some of these had reached a height of 100,000 miles above the solar surface, and, moving with a velocity almost perceptible to the eye, they had doubled their height in ten minutes. They then gradually faded away. Professor Young concluded that the phenomenon indicated the occurrence of an explosion beneath the great prominence, and he suggested that the origin of the coronal streamers might be explained by such events.

Professor Young, in 1870, was the first to photograph the solar prominences. His method, however, did not meet with success, and for twenty years nothing of practical use was accomplished in this line of research. In the year 1872, he, with a small party, visited Sherman, an elevated station in Wyoming, 8,300 feet above the level of the sea, consisting of a little group of houses reached by a gradual ascent of 1,500 miles from the Missouri. The object of the Professor was to get a clear atmosphere for observations on the solar chromosphere. He was enabled to map 273 lines in the chromospheric spectrum, and of these 170 had been previously observed at Dartmouth, while 103 were discovered at Sherman. Observations were also made

of the prominences. The observations at Sherman were very successful. Professor Young, in 1874, was a member of the Government expedition which observed the transit of Venus on December 8 of that year at Pekin. In 1882 he observed the transit of Venus at Princeton, New Jersey. On both of these occasions he observed the spectrum of Venus and perceived doubtful traces of aqueous vapour.

In 1876 Professor Young applied to the Sun Doppler's principle, the object being to measure the rotation, the displacements due to which had been already observed by Dr. Zöllner and Dr. Vogel. The displacements of lines by the Sun's rotation is very small, only $\frac{1}{150}$th part of the interval separating the components of the sodium D-line, which can be divided only by a good spectroscope. Nevertheless, the velocity of rotation was measured by Professor Young. His work and that of other astronomers was followed up by Dr. Dunér, whose wonderful investigation is mentioned in another chapter.

After eleven years' service as Professor at Dartmouth, Professor Young was in 1877 appointed Professor of Astronomy in the College of New Jersey, now known as Princeton University. In the following year he observed the total solar eclipse from near Denver, Colorado. In 1881 he witnessed another great solar eruption, fragments of an exploded protuberance reaching an altitude of 350,000 miles—the greatest height which had been observed. In 1881 Professor Young published in the "International Scientific Series" his valuable work on "The Sun," in which he summarised our knowledge of the great luminary. The book, which went into new editions in 1882, 1888, and 1897, is extremely valuable to all who are interested in solar astronomy. The author is possessed of a clear literary style calculated to make a highly technical subject plain to the general reader. In this volume the distinguished author discusses at length the various sun-spot theories, and, at the time of its publication, was inclined to adopt a modification of Secchi's theory that the spots resulted from eruptive action, which causes also the faculæ and prominences. He was of

opinion that, upon the withdrawal of matter below to form a prominence, the result will be a sinking-in of the surface, the partially cooled vapours settling in the depression. He does not now place so much stress, however, on this opinion. In 1883 Professor Young made important spectroscopic observations on sun-spots, which have been confirmed by the researches of Dr. Dunér. The American astronomer found that in many spots the spectrum of the nucleus is not continuous, but is made up of numerous fine dark lines, which in many cases touch and overlap each other, leaving in some places intervals resembling bright lines. The observations indicate, in Professor Young's view, that the principal absorption which darkens the central portions of spots "is a true gaseous absorption, producing a veritable dark-line spectrum."

In 1883 Professor Young made a series of important observations on Uranus, and measured the polar compression of the planet, the result, which was confirmed by Professor Barnard about ten years later, being confirmatory of that of Signor Schiaparelli. Dusky bands on the surface of Uranus were perceptible to Professor Young. They were very faint in appearance, and resembled the belts of Jupiter.

Professor Young published in 1889 his "General Astronomy," a very valuable work, written in a clear style, and containing much information. In this work he very truly remarks:—"At present the end and object of astronomical study is chiefly knowledge pure and simple; so far as now appears, its development has less direct bearing upon the material interests of mankind than any other of the natural sciences. It is not likely that great inventions and new arts will grow out of its laws and principles, such as are continually arising from physical, chemical, and biological discoveries, though of course it would be rash to say that such outgrowths are impossible. But the student of astronomy must expect his chief profit to be intellectual, in the widening of the range of thought and conception, in the pleasure attending the discovery of simple law working out the most complicated results, in the delight over the beauty and order revealed by the telescope in systems

otherwise invisible, in the recognition of the essential unity of the material universe, and of the kinship between his own mind and the Infinite Reason that formed all things."

Professor Young visited Russia in 1887 for the purpose of observing the eclipse of that year, but the weather was unfavourable, and the expedition was a failure. The total solar eclipse of May 28th, 1900, was observed by him at Wadesborough, North Carolina. The observations were successful, but, to use his own words, "were not fortunate enough to bring out anything new."

Professor Young's contributions to astronomy cannot all be described in a sketch like the present. All that can be mentioned is the publication of his "Views on the Constitution of the Sun," a revision of a sketch written by him in 1877 for Professor Newcomb's "Popular Astronomy." The recent paper appeared in April 1904 in the American periodical, *Popular Astronomy*. Emanating from so great an authority as Professor Young, the paper should be read with great interest, as the result of many years of careful and persistent observation and thought. Professor Young believes the photosphere to consist of "an envelope of clouds, formed by the condensation and combination of such of the solar vapours as are sufficiently cooled by their radiation into space. . . . The photospheric clouds are of course suspended in the surrounding gases and uncondensed vapours, just as clouds float in our own atmosphere." He regards the reversing layer and the chromosphere, as "simply the uncondensed vapours and gases which form the atmosphere in which the clouds of the photosphere are suspended." He says that the contraction theory of Helmholtz, advanced to explain the maintenance of the Sun's heat, is true so far as it goes; but that it is all the truth is now made doubtful by the discovery of radium, which "suggests that other powerful sources of energy may co-operate with the mechanical in maintaining the Sun's heat."

Besides the works already mentioned, Professor Young has published "Elements or Astronomy" (1890), "Lessons in Astronomy" (1891), and "Manual of Astronomy" (1902). "The

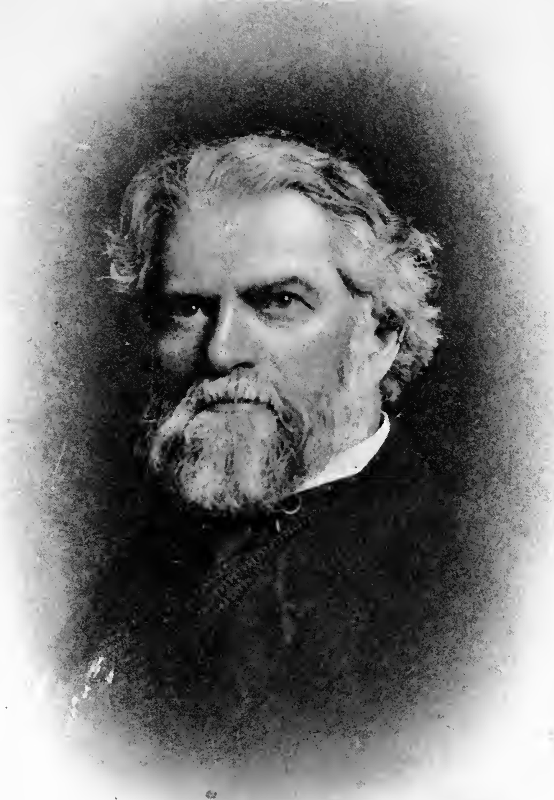
Sun," "Elements of Astronomy," and "Lessons in Astronomy," have been translated into various languages. Professor Young has received numerous honours, including honorary degrees. In 1871 he was elected a member of the Astronomische Gesellschaft, and in 1872 an Associate of the Royal Astronomical Society. He is also a member of the Spectroscopic Society of Italy; in 1882 he presided over the American Association for the Advancement of Science, and he is a member of many other societies. In 1891 he received from the French Academy of Sciences the Janssen Medal for his spectroscopic work. Professor Young is also the inventor of minor instrumental appliances for practical astronomy.

Professor Young's work in the field of solar astronomy, gains for him a lasting place in the science to which he is devoted. His work has done much for the progress of astronomy, especially his observations of the solar chromosphere and of the reversing layer. His place in astronomy is that of a patient and laborious investigator—one of the pioneers of solar spectroscopy.

Simon Newcomb.

Among the astronomers who have given their lives to the solution of the intricate problems presented by the Solar System and the Sidereal Universe, the name of Simon Newcomb occupies a conspicuous place. The position in astronomy of the great American mathematician is a unique one. He has happily combined the qualities necessary for dealing with the problems of sidereal astronomy, with the mathematical powers requisite in the investigation of the infinitely little in astronomical calculation.

Simon Newcomb was born at Wallace, Nova Scotia, on March 12, 1835. Although by birth a Canadian, he is of New England descent, the family having settled in Canada in the latter part of the eighteenth century. His father, John Burton Newcomb, followed during most of his life, the occupation of a country school teacher. It was then, as the astronomer remarks, "an almost nomadic profession, a teacher seldom remaining more than one or two years in the same place." At an early age Simon Newcomb gave indications of a taste for learning, and he was quite unfitted for the life of a farmer, for which he was apparently destined. He writes in his "Reminisences of an Astronomer"—"I had indeed gradually formed from reading, a vague conception of a different kind of world, a world of light, where dwelt men who wrote books and people who knew the men who wrote books, where lived boys who went to college and devoted themselves to learning, instead of driving oxen. I longed much to get



Simon Newcomb.

Photo. by Bachrach & Bro., Washington & Baltimore.)

into this world, but no possibility of doing so presented itself. I had no idea that it would be imbued with sympathy for a boy outside of it, who wanted to learn. True, I had once read in some story, perhaps fictitious, how a nobleman had found a boy reading Newton's "Principia," and not only expressed his pleased surprise at the performance, but actually got the boy educated. But there was no nobleman in sight of the backwoods of Nova Scotia."

In 1851 young Simon Newcomb, then sixteen years of age, paid a visit to Moncton, New Brunswick, the residence of his grandfather, Mr. Prince, who suggested that he should "learn to do something to make a living." It was agreed that the lad should become a carpenter. But before Mr. Prince could see a carpenter, he was taken ill, and the medical man called proved to be a certain Doctor Foshay, who practised the botanic system of medicine. Young Newcomb engaged himself to be his assistant and pupil on the following terms:— "S.N. to live with the doctor, rendering him all the assistance in his power in preparing medicines, attending to business, and doing generally whatever might be required of him. The doctor, on his part, to supply S.N.'s needs in food and clothing and teach him medical botany and the botanic system of medicine." In this situation the young man remained two years, but with no result. The doctor gave him absolutely no education in medicine, nor did he even let him out to visit a patient. In addition to this, the doctor was exceptionally formal, grave and silent towards his young pupil, and a certain mystery seemed to enshroud his personality, so that the pupil felt a certain awe which prevented his asking any questions regarding the doctor's intentions. To escape from this drudgery, Simon Newcomb determined to desert Dr. Foshay and join his father, who had now settled in New England.

In his "Reminisences," Professor Newcomb tells us of his journey to the States. He was on the road before daybreak, and walked until late at night, covering fifty miles, and only stopping for a few minutes to rest under the shadow of a tree or to bathe his feet in a brook. To make things worse, he

missed the stage coach which he had intended to travel by. Fortunately, however, he was entertained at a house for the night. In his own words, "Thus ended a day to which I have always looked back as the most memorable of my life. I felt its importance at the time. As I walked and walked, the question in my mind was, what am I doing and whither am I going? Am I doing right or wrong? Am I going forward to success in life or to failure and degradation? Vainly, vainly, I tried to peer into the thick darkness of the future. No definite idea of what success might mean could find a place in my mind. I had sometimes indulged in day-dreams, but these came not to a mind occupied as mine on that day. And if they had, and if fancy had been allowed its wildest flight in portraying a future, it is safe to say that the figure of an honorary academician of France, seated in the chair of Newton and Franklin in the Institute, would not have been found in the picture.

"As years passed away I have formed the habit of looking back upon that former self as upon another person, the remembrance of whose emotions has been a solace in adversity and added zest to the enjoyment of prosperity. If depressed by trial, I think how light would this have appeared to that boy had a sight of the future been opened up to him. When, in the halls of learning, I have gone through the ceremonies which have made me a citizen of yet another commonwealth in the world of letters, my thoughts have gone back to that day; and I have wished that the inexorable law of nature could then have been suspended, if only for one moment, to show the scene that Providence held in reserve."

For two years Simon Newcomb was a teacher in Maryland. Soon afterwards he made the acquaintance of Professor Henry, of the Smithsonian Institution, and that gentleman, along with Professor Hilgard, assisted him in his appointment as computer on the "American Nautical Almanac." Shortly afterwards he entered the Lawrence Scientific School at Harvard, and was graduated Bachelor of Science in 1858. He resided for three years at Cambridge, and continued his mathematical studies. In 1860 he was one of a party which visited the Saskatchewan

region to observe the total solar eclipse of that year, but clouds prevented a view of the eclipse. In 1860 he published his first elaborate work "Secular Variations and Mutual Relations of the Orbits of the Asteroids." His object was to settle the question of the origin of the Asteroids, and to either prove or disprove Olbers' hypothesis that they were fragments of an exploded planet. Accordingly, he calculated the changes of the orbits of the Asteroids back for several thousand years, and was enabled to prove that the orbits had never passed through a common point of intersection, thus definitely disproving Olbers' theory. Of course, as Professor Newcomb remarks, it was a disappointment not to discover the reality of the explosion, but, "next best to finding a thing is showing that it is not there."

Another of Mr. Newcomb's early labours was that regarding the distance of the Sun. The observations of the opposition of Mars, in 1862, in his hands, made out the distance of the Sun as $92\frac{1}{2}$ millions of miles. Many years later, in 1890, he investigated the observations of the transits of Venus in 1761 and 1769, from which Encke had deduced a parallax of 95,000,000 miles. Professor Newcomb, after eliminating the optical errors accompanying the observations, arrived at a parallax not differing much from those found by modern research. In 1861 he was appointed Professor of Mathematics in the United States Navy and Astronomer at the Naval Observatory, where he did active observing work for several years. It was plain, however, that Professor Newcomb was a better mathematician than observer, and, accordingly, his investigations have been almost exclusively devoted to mathematical astronomy. In 1874 he was a member of the commission appointed by Congress to arrange and complete the plans for the various parties sent to observe the transit of Venus.

In calculating the orbits of all the planets, Professor Newcomb has acquired a high reputation. His paper on the Asteroids was followed by "An Investigation of the Orbit of Neptune" in 1867, and "An Investigation of the Orbit of Uranus" in 1874. In 1870 he took up the important subject of the motion of the Moon, which has occupied the attention of such

men as Laplace, Plana, Delaunay and Adams, and his results were published eight years later. His investigations tended to reduce the amount of acceleration of the Moon's mean motion which Laplace's theory did not account for. He further showed, in the words of Miss Clerke, "that small residual irregularities are still found in the movements of our satellite inexplicable by any known gravitational influence." His studies of the Moon's motion led him to the idea that something could be learned from old observations on our satellite. For this purpose, he determined to visit Paris to search the records of the Observatory for these observations. An opportunity soon presented itself. On the occasion of the total solar eclipse of December 1870, Professor Newcomb visited Europe for the purpose of observation. During his visit to Europe he was introduced to the greatest English, German, and French astronomers, meeting in England Adams and Huggins, in Germany Argelander and Hansen, and at Pulkowa Professor Otto Struve. At this time the Franco-Prussian War was proceeding, and Professor Newcomb, who was then in Germany, took almost the first train that travelled to France. In Paris he was received at the Observatory by Delaunay, the great French mathematician, at the time when Paris was ruled by the Commune and besieged by the national forces. Professor Newcomb, however, was employed searching the Observatory records for the observations on the Moon's motion, which he studied exhaustively. He remarks that "the studies had to be made within hearing of the besieging guns; and I could sometimes go to a window and see flashes of artillery from one of the fortifications of the south."

On the death of Professor Winlock in 1875, Professor Newcomb was offered the post of director of the Harvard College Observatory. As he remarks, such would have influenced all his future activity. About the same time he received the offer of the office of superintendent of the "Nautical Almanac," which he ultimately accepted, holding the office for twenty years, until his retirement at the required age of sixty-two in 1897. Although urged to accept the post

at Harvard, he finally declined "perhaps unwisely for myself," he says, "though no one who knows what the Cambridge Observatory has become under Professor Pickering can feel that Harvard has any cause to regret my decision." On September 15, 1877, he took charge of the "Nautical Almanac," receiving at the same time the appointment of Senior Professor of Mathematics in the U.S. Navy. His connection with the Observatory was now severed.

At the Observatory, however, he had accomplished some valuable work. He played a leading part in the construction of the 26-inch telescope. He was selected to test the glasses, and in 1873 he visited Cambridge, Mass., for that purpose. He writes of his first observation—"I was filled with the consciousness that I was looking at the stars with the most powerful telescope that had ever been pointed at the heavens, and wondered what mysteries might be unfolded. The night was of the finest, and I remember, sweeping at random, I ran upon what seemed to be a little cluster of stars, so small and faint that it could scarcely have been seen in a smaller instrument, yet so distant that the individual stars eluded even the power of this instrument. What cluster it might have been it was impossible to determine, because the telescope had not the circles and other appliances necessary for fixing the exact location of an object. I could not help the vain longing which one must sometimes feel under such circumstances, to know what beings might live on planets belonging to what, from an earthly point of view, seemed to be a little colony on the border of creation itself." Professor Newcomb observed the star *Procyon* in the hope of discovering its hypothetical companion, but he was unsuccessful. He examined the planet Neptune in search of new satellites, but he was unsuccessful in this also.

In 1878 Professor Newcomb published his masterly volume "Popular Astronomy." His conclusions as to the construction of the heavens are of great interest. After a discussion of the views of Kant, Lambert, Herschel, Struve and others, he comes to the conclusion that the Stellar Universe does not possess the form of stability which is seen in our Solar System,

and that only the motions of the various stars prevent them from falling towards a common centre. Professor Newcomb distinctly rejects the idea of Mädler and others that the stars revolve round some central body. When we attempt to unravel the laws of stellar motion, he points out, we are brought face to face with the subject of their evolution. He accepts the Nebular Hypothesis in its general form, but remarks that the theory cannot be proved beyond all doubt until the Sun shall be found growing smaller by actual measurement, or the nebulæ be actually seen to condense into stars and systems.

Professor Newcomb's investigation of the motion of the Solar System through space deserves some mention. While determining the amount of the precession of the equinoxes, he incidentally determined the solar motion. The position which he found for the solar apex does not differ much from those found by Dr. Kapteyn and Dr. Campbell. In 1884 Professor Newcomb published at Washington his "Measure of the Velocity of Light," the result of experiments from 1880 till 1882. These experiments were conducted on an impressive scale, the fixed and revolving mirrors by which the velocity of light was measured being set up on opposite sides of the Potomac River in Washington. The result arrived at was that light travels at a rate of 186,328 miles a second.

In 1882 Professor Newcomb observed the transit of Venus from the Cape of Good Hope. "The sky on the day of the transit" he writes, "was simply perfect. Notwithstanding the intensity of the Sun's rays, the atmosphere was so steady that I have never seen the Sun to better advantage. So all our observations were successful." In 1884 Professor Newcomb accepted the chair of Mathematics and Astronomy in the John Hopkins University, Baltimore. He held this position till 1893. He also assisted in the equipment of the Lick Observatory, California, which began activity in 1888.

In Sidereal Astronomy Professor Newcomb has earned a world-wide reputation. He has made many investigations of the motions of the stars. He found that a rate of twenty-five miles a second is the "critical velocity" for the Sidereal

System, and that a star moving with a greater velocity would pass through the Milky Way. The star known as 1830 Groombridge, which Professor Newcomb has called the "runaway star," has a velocity of 200 miles a second, which is sufficient to counterbalance the attraction of all the other bodies in the universe. Such stars are therefore to be regarded as visitors to the Sidereal System.

Some remarkable investigations on stellar distribution were made by Professor Newcomb. He says, "We mark out on a map of the Milky Way the brightest regions—that is, those which include the densest agglomeration of very faint stars. We also mark out the darkest regions, including the Coal Sack." Making use of the maps of Heis and Gould for the northern and southern Milky Way respectively, Professor Newcomb made a careful enumeration of the number of lucid stars in certain bright regions, and the number of lucid stars in the dark regions. "The remarkable and unexpected conclusion was reached that the darker regions of the Galaxy are only slightly richer in stars visible to the naked eye than other parts of the heavens, while the bright areas are between 60 and 100 per cent. richer than the dark areas." This discovery is of fundamental importance, showing a distinct unity of plan in the structure of the Universe, and proves the close connection between the lucid stars and the star clouds of the Galaxy.

In his recent work "The Stars"—an admirable volume and an important contribution to astronomical science—published in the autumn of 1901, Professor Newcomb discusses the question of the construction of the Stellar Universe. He comes to the conclusion that the stars in our universe are limited in number, whether or not there are universes beyond. He has brought before his readers Olbers' calculation, that were the stars infinite in number, the entire heavens would shine with the brilliance of the Sun. Therefore Professor Newcomb has shown that we must abandon the idea of the infinity of *our* universe. His conclusions on the construction of the heavens are given at the close of his book on "The Stars,"

and may be reproduced here as the most trustworthy results yet reached:—

1. The stars differ enormously in their actual luminosity. Some are thousands or tens of thousands of times more luminous than the Sun; others only one hundredth or one thousandth as luminous.

2. The more luminous stars are generally the hotter, the bluer, and the rarer in their constitution. They are, as it were, inflated masses of rare and intensely incandescent gas. Hence the stars do not differ in mass so widely as in luminosity.

3. The bluest and most luminous stars are situate mainly in the region of the Milky Way. There is some reason to suspect that in this region the more densely the stars are agglomerated the larger and more luminous they are.

4. That collection of stars which we call the Universe is limited in extent. The smallest stars that we see with the most powerful telescopes are not, for the most part, more distant than those a grade brighter, but are mostly stars of less luminosity, situate in the same region. This does not preclude the possibility that there may be other collections of stars of which we know nothing.

5. The boundary of our universe is probably somewhat indefinite and irregular. As we approach it, the stars may thin out gradually. The parallax on the boundary is probably nowhere greater than 0″001 and may be much less. The time required for light to pass over the corresponding interval is more than three thousand years.

6. The universe extends further around the girdle of the Milky Way than towards the poles of the girdle. But, in every direction it extends beyond the limit within which the proper motions of the stars have yet been determined.

7. It does not yet seem possible to decide whether the agglomerations of the Milky Way lie on the boundary of the Universe or not. The number of lucid stars which they contain seems to militate against the view, though not strongly, because of the possible great luminosity of the galactic stars.

8. The total number of the stars is to be counted by hundreds of millions.

9. Outside the galactic region the stars in general show no tendency to collect into systems or clusters, but are mostly scattered through space with some approach to uniformity.

In 1902 Professor Newcomb contributed the article on Astronomy to the "Encyclopædia Brittanica." His most recent works are "Astronomy for Everybody," published in 1903 with an introduction by Sir Robert Ball, and "The Reminiscences of an Astronomer," from which most of the details in this chapter have been derived. As a reward for his labours in the science of Astronomy, many honours have been bestowed upon Professor Newcomb. He received in 1874 the Gold Medal of the Royal Astronomical Society, having, two years before, been elected an Associate. From the Univesity of Leyden he received the great Gold Huyghens Medal, given only once in twenty years. Many universities—including Edinburgh, Heidelberg, and Padua — have conferred upon him honorary degrees, the latter being conferred on him, on the occasion of the Galileo tercentenary, in company with Helmholtz, Kelvin, Schiaparelli, Tisserand, Brédikhine, and Gyldén. He was elected in 1895 one of the eight foreign associates of the Institute of France, and was the first American thus honoured. Professor Newcomb became a member of the National Academy of Sciences in 1869, and was Vice-President from 1883 to 1889. In 1877 and 1878 he presided over the American Association for the Advancement of Science. By presents the Czar of Russia and the Japanese Government have shown their appreciation of his assistance to them in the acquisition of their large telescopes.

Unlike many other astronomers, whose attention is entirely taken up with the one subject, Professor Newcomb, to use the expression of Sir Robert Ball, "is as versatile as he is profound." He has been President of the American Society of Psychical Research. He has also paid much attention to political economy, which he pursues as a recreation, and has published several books on the subject. He has, it may be stated,

recently made his appearance as a distinguished novelist. It will be thus seen that in many ways, as we have already said, Professor Newcomb occupies a unique place in the world of science. Although in retirement, he still pursues the study of astronomy, and we may expect from him further contributions to the science. At all events, it may be confidently asserted that Simon Newcomb has left an enduring mark on astronomical science. He has gained a never-fading reputation, and must rank as one of the greatest of modern astronomers.

Giovanni Virginio Schiaparelli.

(Photo. by G. B. Ganzini, Milan.)

Giovanni Virginio Schiaparelli.

To the great Italian astronomer who forms the subject of this chapter, much of our knowledge of modern astronomy is due. His studies of meteoric astronomy, of Mars, Venus, and Mercury, of double stars, and of stellar distribution, have given him a place second to none among living students of the heavens. Like all other great scientists, he has conducted his researches with that scrupulous accuracy, that love of truth, and that perseverance and patience which alone will elucidate the problems presented by the starry skies, and will further the progress of—to use Professor Schiaparelli's own expression—"the science of infinity and eternity."

Giovanni Virginio Schiaparelli was born at Savigliano, in Piedmont, on March 14, 1835. After elementary education in the Gymnasium and Lyceum of his native town, he entered the University of Turin as a student of mathematics and architecture, in November 1850, when in his sixteenth year. At the University he studied mathematics under the distinguished astronomer and mathematician, Plana, whose name is closely associated with his work regarding the motion of the Moon. In 1854, he took his degrees in engineering and architecture, but, as his mind did not lie in either of these directions, he decided to devote himself to the study of astronomy. He was in financial difficulties, and the Government of Sardinia assisted him with a small sum of money annually, which he utilised in undertaking a journey to Berlin, where he attended the astronomical lectures of Encke, from the beginning of 1857 to the middle of 1859.

In June 1859, Schiaparelli became assistant at the Observatory of Pulkowa, near St. Petersburg, where he remained for a year. On the formation of the Kingdom of Italy, however, he was recalled to his native country as assistant to the astronomer Carlini, in the Brera Observatory at Milan. Before he had been one year in his new post, his name became famous by his discovery, at Milan, on April 29, 1861, of Hesperia, the sixty-ninth of the Asteroids. In September 1862, on the death of Carlini, Signor Schiaparelli became director of the observatory, and shortly afterwards began the observations which have rendered the name of the Brera Observatory famous throughout the world of science.

Professor Schiaparelli's first great discovery, the connection between comets and meteors, was announced in 1866. It may safely be described as one of the most epoch-making discoveries of modern times. "The steps," writes Miss Clerke, "by which this curious connection came to be ascertained were many, and were taken in succession by a number of individuals. But the final result was reached by Schiaparelli of Milan, and remains deservedly associated with his name."

The great shower of meteors in November 1866 attracted the attention of astronomers all over the world to meteoric astronomy. Before this, however, Signor Schiaparelli had been working at the question. In four remarkable letters addressed to Secchi at Rome, towards the end of 1866, and reprinted in the *Bulletino* of the Observatory of the Collegio Romano, he showed that meteors were members of the Solar System, possessed of a greater velocity than the Earth, and travelling in orbits resembling those of comets in their eccentricity, in the fact that they moved in no particular plane, and that their motion was performed in both directions. He also came to the conclusion that comets and meteors are bodies drawn into the Solar System from interstellar space. He then computed the orbit of the Perseids, assuming it to be parabolic, and reached the astonishing conclusion that the meteoric orbit was identical with that of the bright comet of August 1862. He showed, in fact, that the comet was merely a larger

member of the meteor swarm. Early in 1867 Professor Schiaparelli found that the November meteors or Leonids move in the same orbit as the comet discovered by the German astronomer Tempel at Marseilles, in the end of 1865. His conclusions regarding the nature of comets are so remarkable, that they may be summarised here. He was led to regard comets as cosmical clouds formed in space by "the local concentration of celestial matter." He then remarks that a cosmical cloud seldom penetrates to the interior of the Solar System, "unless it has been transformed into a parabolic current," which may occupy years, or centuries, in passing its perihelion, "forming in space a river, whose tranverse dimensions are very small with respect to its length; of such currents, those which are encountered by the earth in its annual motion are rendered visible to us under the form of showers of meteors diverging from a certain radiant."

Professor Schiaparelli next points out that when the current of meteors encounters a planet, the resulting perturbations cause some of the meteoric bodies to move in seperate orbits forming the bolides and aerolites which fall from the sky at intervals. "The term *falling stars*," he says, "expresses simply and precisely the truth respecting them. These bodies have the same relation to comets that the small planets between Mars and Jupiter have to the larger planets." Professor Schiaparelli's researches on meteors were further developed in 1873, in his remarkable work, "Le Stelle Cadenti," which is, according to Sir Norman Lockyer, one of the greatest contributions to astronomical literature which the nineteenth century produced. The volume was founded on three lectures delivered before the Royal Institute of Lombardy, after the meteoric shower of November 27, 1872. In his third chapter, Professor Schiaparelli says:—"The meteoric currents are the product of the dissolution of comets, and consist of minute particles which certain comets have abandoned along their orbits, by reason of the disintegrating force which the Sun and the planets exert on the rare material of which they are composed." The dissolution

of a comet, or cosmical cloud, Professor Schiaparelli points out in "Le Stelle Cadenti," is caused by the action of the Sun and planets on the different particles, thus causing the particles to move in different orbits. The result is that the comet is elongated, and becomes a meteoric stream. These facts are regarded by him as the result of a diligent examination of all the facts gathered by various investigators. In support of his views, he refers to the division and disappearance of Biela's comet, and to the granulated appearance of several cometary nuclei.

In 1872, Professor Schiaparelli received the Gold Medal of the Royal Astronomical Society for this wonderful discovery. The astronomer Lassell, then President of the Society, said of his labours—"It appears to me that we can scarcely speak of them too highly or overrate their importance." It is always interesting to have one eminent man's estimate of another, and the following is what Mr. Denning, the great meteoric observer, says of Professor Schiaparelli's work—"The opportunity was a remarkable one, and Schiaparelli accepted it. Marshalling his facts in proper array, he brought the skill of the mathematician and the reasoning of the logician to bear on them successively. He proved himself the man for the hour."

In the observation of the surfaces of the planets, Professor Schiaparelli's reputation is an enduring one. He has opened a new era in the study of our nearest planetary neighbours, Mercury, Venus, and Mars. The words of Professor Simon Newcomb regarding planetary observations are no exaggeration —"Among the individual observers Schiaparelli may be assigned the first place, in view of his long-continued study of the planets under a fine Italian sky, the conscientious minuteness of his examinations, and his eminence as an investigator."

In 1877, Professor Schiaparelli commenced his memorable series of observations on Mars. When the illustrious Italian astronomer began the observations by which his name has been rendered justly famous, our knowledge of the surface of the red planet was very limited; astronomers had recognised only the existence of Proctor's "continents" and "oceans," and the white spots at the north and south poles. Professor Schiaparelli

has revolutionised our knowledge of the surface of the red planet. In September 1877, during the very favourable opposition of that year, while executing a trigonometrical survey of the disc, he found that the reddish-ochre portions, or "continents," were cut up by numerous dark lines, thousands of miles in length. To these he gave the name of *canali*. "The world, however," writes Mr. Percival Lowell, "was anything but prepared for the revelation, and when he announced what he had seen, promptly proceeded to disbelieve him." There the matter rested for 1877.

When the planet came to opposition in November 1879, Professor Schiaparelli again recognised the canals, which revealed the same appearance as they did two years previously. Towards the end of the year he was amazed to find that one of the canals had become double—that is to say, another canal ran parallel to the original one. He suspected optical illusion, and changed his telescopes and eyepieces; but it was apparent that the phenomenon was real. He waited for the next opposition to see if his observations would be confirmed. In December 1881, he found, much to his surprise, that about twenty of the canals had become double, a new canal running parallel to the original one at a distance of from 200 to 400 miles. While other astronomers were sceptical as to the reality of the discovery, Professor Schiaparelli confirmed his previous observations on each occasion, and at the unfavourable opposition of 1888, he declared that the canals had all the distinctness of an engraving on steel with the magical beauty of a coloured painting.

For nine years he was the only astronomer who saw the canals, and this added to the general scepticism as to their reality; but he had the whole field of observation to himself, and he succeeded in practically proving the reality of the canal system. As Mr. Lowell, one of his most ardent admirers, says, "He won. The voices that ridiculed him are all silent now. To-day the canals of Mars are well-recognised astronomic facts, and constitute one of the most epoch-making astronomic discoveries of the nineteenth century."

In 1886, the Martian canals were recognised by the late M. Perrotin, and his assistant, the late M. Thollon, at Nice, and since then have been observed by Professor W. H. Pickering in South America, Mr. Lowell in Arizona, the astronomers of the Lick Observatory and other observers. To see them, an exceptionally fine atmosphere is necessary. Professor Schiaparelli continued his observations on Mars until 1890, but imperfect eyesight prevented him following the planet in subsequent oppositions. His fifteen years' study of Mars led him to the belief that the climate of Mars "must resemble that of a clear day on a high mountain," that the polar caps were snow and ice, the reddish-ochre portions of the disc, land, and the blue-green areas, water, the canals being waterways lined on either side by banks of vegetation. He further came to the conclusion that the duplication of the canals is dependent on the Martian seasons. He says of the idea that the canals are the work of intelligent beings—"Io mi guardero bene dal combattere questa supposizione, la qualle nulla include d' impossibile." (I should carefully refrain from combating this supposition, which involves no impossibility).

In 1882 Professor Schiaparelli began the study of the much-neglected planet, Mercury. His observations were made with an 8-inch, and latterly with an 18-inch, refractor. Instead of observing the planet through the evening haze, he followed it by day, observing it on one occasion when only six diameters distant from the solar disc, "a good proof," as Mr. Gore remarks, "of the excellence of the instrument as well as the keen sight of the observer." His object was to ascertain the period of the planet's rotation, which was believed by Schröter and Bessel to be about 24 hours. The Milan astronomer followed the planet hour by hour, and found that the markings visible remained fixed. At length, after seven years' observation, Professor Schiaparelli announced on December 8, 1889, that Mercury performs only one rotation during its revolution round the Sun—in fact, that one side of the planet had continuous day and the other everlasting night. He also stated the movement of libration resulting from the uniform motion

of Mercury on its axis combined with its irregular motion in its orbit. The result is that the Sun rises and sets on one-fourth of the surface of the planet. Professor Schiaparelli's observations indicated that Mercury was a much spotted globe, enveloped in a tolerably dense atmosphere, the axis of rotation being perpendicular to the plane of the planet's orbit. He also judged that certain brownish stripes and streaks were permanent, and he formed a chart of the Mercurial markings.

The observations on Mercury were sufficiently startling, but there was more to follow. Professor Schiaparelli made his well-known studies on Venus at the same time as those on Mercury, with the object of determining the rotation period, which was previously believed to be about 24 hours. His observations were made in daylight and, instead of looking at Venus daily, he followed it hour by hour. He concentrated his attention on round white spots and these were found to be, like the spots on Mercury, fixed in position. His conclusions were summed up in five notes read to the Milan Academy in 1890, the first four being devoted to the history of observations on the markings on Venus—with a view to determining the rotation period—by Cassini, Bianchini, Herschel, Schröter, Di Vico, and others. In the fifth note he announced that the period of rotation must be between six and nine months in length, probably 225 days, equal to the period of revolution. Although rejected by some and doubted by others, the conclusions were supported by observations previously made by Dr. Vogel, and confirmed in 1890 by the late M. Perrotin, in 1895 by Professor Tacchini, and in 1897 by Mr. Lowell, who arrived at the conclusion that the rotation of Venus was performed in exactly 225 days. In 1895 Professor Schiaparelli made a second series of observations on Venus and confirmed his previous result.

Professor Schiaparelli's conclusions regarding Mercury and Venus have given rise to much discussion. Although they were contradicted by many astronomers, they are probably correct and are distinctly confirmed by Professor G. H. Darwin's theory of tidal friction, which is discussed in our chapter on

that distinguished mathematician. Additional weight is given to the observations by the fact that Professor Schiaparelli's observations have been distinguished by his keen-sightedness and care. He has taken every precaution to avoid all the disturbances resulting from personal equation, and has found it well to adopt the rule, "to abstain from everything which could affect the nervous system, from narcotics and alcohol, and especially from the abuse of coffee, which I have found to be exceedingly predjudicial to the accuracy of observation."

In 1875 Signor Schiaparelli commenced his important observations on double stars, having picked out difficult and interesting pairs for remeasurement with his exquisite telescopes in the clear air of Milan. His first measures extending from 1875 to 1885, were published in 1887. By 1899 he had obtained altogether 11,000 measures of double stars, but the greater part of his observations are still unpublished. He discovered some close double stars, including ε Hydræ, and distinguished himself in the calculation of the orbits of binary stars. Observations on Uranus were made by Professor Schiaparelli at Milan in 1883. He assigned to the planet a polar compression of one-eleventh, confirming the observations of Professor Young.

An interesting memoir on the apparent distribution of the stars visible to the naked eye was published by Professor Schiaparelli in 1889. His work was based on the photometric measures of stellar magnitude by Professor E. C. Pickering and the catalogue of the late Dr. Gould. He constructed a series of planispheres showing the star-density in every part of the heavens for stars of various magnitudes. He divided the entire sky into thirty-six zones and thus formed 1800 areas, not very different from each other, noting the star-density of each area. These researches proved that the stars visible to the naked eye have a tendency to crowd towards the plane of the Galaxy. For instance, supposing the Milky Way itself were quite invisible to us, we could still trace its course in the heavens by the crowding of the lucid stars towards the galactic plane. This is a great discovery, proving

the connection between the Galaxy and the brighter stars. These researches of Professor Schiaparelli are confirmed by the investigations of Mr. Gore and the late Mr. Proctor.

Some mention must be made of Signor Schiaparelli's masterly handling in the same paper, of the theory of the extinction of light in interstellar space, which was so ably supported by Wilhelm Struve. After a profound discussion, he concludes that, if we accept the theory, we must believe that the Sun is situated in a spherical cavity comparatively free from stars, the stars increasing in number with increase of distance. The supposed extinction in the ether would produce an absorption in the light of the stars when observed by means of the spectroscope. The greater the distance, the greater would the spectrum be affected; but no such absorption has ever been observed. The great Italian astronomer concludes that the hypothesis is unnecessary and improbable, a view shared by the greatest authorities on the subject, Professor Newcomb, Mr. Gore and Professor Seeliger. In Professor Schiaparelli's opinion, if any extinction of light does take place, it is due not to absorption in the ether—which he believes does not act like a gas—but to particles of matter in interstellar space, similar to the particles constituting comets' tails and meteors. This might produce an appreciable extinction in the light of very distant stars. The most important result, however, of Professor Schiaparelli's investigation is his demonstration of the fallacy of the original theory of extinction.

In a paper published in 1896, Professor Schiaparelli investigates the question of the supposed change of colour in *Sirius*, which was described as red by Ptolemy and other ancient writers. It is now white with a tinge of blue. Several astronomers, therefore, consider that the colour of *Sirius* has really changed within the last two thousand years. Signor Schiaparelli, however, came to the conclusion that the word "red" as used by the ancients might mean either "fiery" or "blazing," probably suggested by the brilliancy of the great star and the changing of its colour near the horizon. In addition to this, it seems highly improbable that the star could

have changed its colour in so short a period of time as two thousand years.

Professor Schiaparelli retired, through illness, from the post of direcror of the Brera Observatory, in November 1900, after holding that position for a period of thirty-eight years. He was succeeded by his assistant, Signor Celoria, who has paid great attention to stellar astronomy, especially the Milky Way, and whose life-work is described in another chapter. Although in retirement, Professor Schiaparelli still pursues the study of astronomy. In a recent letter to the present writer he remarked that the publication of his observations on double stars will be the object of his work for several years to come.

Professor Schiaparelli's latest contribution to astronomy is his work "L'Astronomia nell' Antico Testamento," published at Milan in 1903. In this work he deals with the numerous allusions to astronomy in the Old Testament. He points out that though the Hebrews were not leaders of scientific thought, they were impressed and overwhelmed by the wonders of the starry heavens. He shows that several passages in the Bible, if rightly interpreted, prove that the Hebrews had observed celestial phenomena. Thus, Professor Schiaparelli is also of opinion that two passages in Joel and Amos are allusions to eclipses of the Sun and Moon, which he considers "were not unknown to the Hebrews." In Joel we read, "The Sun shall be turned into darkness and the Moon to blood"; Professor Schiaparelli interprets the latter as an allusion to the remarkable red colour of the Moon during eclipse. In Amos, again, we read: "And it shall come to pass in that day, saith the Lord God, that I will cause the Sun to go down at noon, and I will darken the Earth in the clear sky"—plainly an allusion to a total solar eclipse. Professor Schiaparelli discusses the constellations known to the Hebrews, and comes to the conclusion that they were acquainted with Ursa Major, Ursa Minor, the *Hyades* and *Aldebaran*, Orion and the *Pleiades*. He is of opinion that "the chambers of the south" mentioned by Job is an allusion to that brilliant portion of the southern heavens distinguished by the bright stars of Argo, the Cross,

and the Centaur, which at that time rose above the southern horizon of Palestine.

The enigmatical passage, "Canst thou lead forth the Mazzaroth in their season," seems to have received its explanation from Professor Schiaparelli. He points out that there is, in the Latin version of the Old Testament, an allusion to the Sun, the Moon, Mazzaloth,* and all the host of heaven." He identifies Mazzaloth with Mazzaroth, and concludes that Mazzaroth "in its season" is a reference to the planet Venus, the most brilliant of the heavenly bodies, excepting the Sun and Moon. Professor Schiaparelli's explanation is the most probable yet offered. We should not expect that such a brilliant object as Venus would be overlooked by the Hebrews. But in a chapter like this, only a brief sketch can be given of Professor Schiaparelli's masterly work.

In this sketch we cannot describe each of Professor Schiaparelli's contributions to modern astronomy. We have been only able to indicate the principal ones. He has paid much attention to the history of ancient astronomy, and in 1875 gave an explanation of the homocentric spheres of Eudoxus. He has also studied the meteorological calendars of the ancients, the astronomical theories of the Greeks, and pre-Copernican systems of astronomy. His investigations of the influence of the Moon on the weather,—in which he reaches a negative conclusion,—on the variation of latitude, and on the distances of the stars, have added to a reputation already of the highest.

By his unwearied labours Professor Schiaparelli has placed himself in the front rank of astronomers. His researches have enormously extended our knowledge of Mercury, Venus, and Mars, our three nearest planetary neighbours, of comets and meteors, and of the distribution of the stars. He has created a new epoch in various branches of astronomical research. His devotion to astronomy, his singularly accurate observations, and his wonderful discoveries have secured for him an exalted position among the greatest astronomers of modern times.

* Translated in the Authorised Version as "the planets."

Sir Joseph Norman Lockyer.

One of the most eminent astronomers of the present day is Sir Norman Lockyer, Professor of Astronomical Physics in the Normal School of Science, and Director of the Solar Physics Observatory at South Kensington. To Sir Norman Lockyer we owe much of our knowledge of the constitution of the Sun and of the stars, and his investigations, particularly in Solar astronomy, have gained for him a lasting reputation.

Joseph Norman Lockyer was born at Rugby on May 17, 1836. Educated in various private schools and on the Continent, he became a clerk in the War Office at the age of twenty-one. In 1865 he received from Lord de Grey the appointment of editor of *Army Regulations*, and, along with Mr. Thomas Hughes, he improved the legislation of the War Office. Meanwhile he had for some time devoted himself to astronomy and was elected a Fellow of the Royal Astronomical Society in 1860. To the Society he contributed a paper on the planet Mars, to which he at first devoted much attention. His observations at the opposition of 1862 established a "marvellous agreement" with Beer and Mädler's results in 1830, leaving no doubt as to the permanency of the chief features amid "daily, nay, hourly" variations caused by transits of clouds.

About the same time Mr. Lockyer began to observe the Sun, and in 1866 proposed a new method of observing the red flames in daylight. For that purpose he ordered the same year a strongly dispersive spectroscope, but it was not until October 16, 1868,

that he had the instrument in his hands. On October 20, he applied the spectroscope to the Sun, and observed the spectrum given out by the red flames. It appeared that M. Janssen, the eminent French astronomer, had made the same discovery at the time of the total Solar eclipse visible in India on August 18, 1868; but the credit of the discovery must be equally divided between Janssen and Lockyer. To commemorate this discovery a medal was struck in 1872 by the French Government, on which the Englishman and the Frenchman appeared as co-discoverers. Another of Lockyer's early discoveries was made in 1868. Working in conjunction with Dr.—afterwards Sir Edward—Frankland, the eminent chemist, he ascertained the existence in the Sun of a previously unknown element. It was named helium or the sun-element. This discovery was of vast importance, and helium was known to exist in the Sun, and even in the nebulæ, before it was found on the Earth in 1895.

Throughout his scientific career Professor Lockyer has paid much attention to the Sun. On March 4, 1866, he applied the spectroscope to the direct examination of the Solar surface. His investigations into the cause of the darkening of sun-spots showed that these obscurations were caused, not by any decrease of the emissive power, but by an increase of the absorption caused by the mass of cool vapours. In 1872 Professor Lockyer commenced investigating the number of elements in the Sun. When he began his observations fourteen substances were recognised as common to both the Earth and Sun. In six years he had increased the list to thirty-three. Several of these, however, have proved illusory. In 1878 Professor Lockyer detected carbon in the great luminary, and also ascertained the presence of vanadium. In 1870 he applied to the Sun Doppler's principle, so successfully used by Sir William Huggins in regard to the stars. Professor Lockyer's idea was to investigate the meteorological condition of the Sun. His observations showed the existence of gigantic cyclones. By means of the displacements of the hydrogen lines, the existence was ascertained of incandescent whirlwinds at

speeds varying to 250 miles a second. In 1869 the eminent astronomer was elected a Fellow of the Royal Society, and the following year he became secretrary of the Duke of Devonshire's Royal Commission on Scientific Instruction. In 1870 he was appointed lecturer on astronomy at the Normal School of Science at South Kensington, and some time later became Professor of Astronomical Physics. He was appointed to the Science and Art Department in 1875, and in that year was made Correspondent of the French Academy of Science, receiving also the Janssen Medal.

On December 12, 1878, Professor Lockyer read before the Royal Society his hypothesis of "chemical dissociation" in the celestial bodies. He concluded that the elements,—which on the Earth cannot be divided—such as calcium, oxygen, nitrogen, etc., are broken up by the intense heat of the Sun and stars into simpler forms. According to Professor Lockyer, this is confirmed by observation on the solar spectrum. From 1875 to 1877 he mapped a portion of the solar spectrum from wave-lengths 3,800 to 4,000 on such a great scale, that had the chart been completed down to the infra-red portion of the spectrum, its length would have been half a furlong. Observations by means of photography revealed the presence of what he called "basic lines," and which he supposed to prove the existence of matter in simpler forms. Professor Young, however, threw doubt on Professor Lockyer's conclusions. Observations on sun-spots, from November 1879 to February 1888, strongly supported the "dissociation hypothesis." The spectra of 850 spots were exhaustively studied by Professor Lockyer, and he was enabled to prove that at the sun-spot minimum, the lines of iron, titanium, nickel, etc., were conspicuous, while at the maximum these lines had ceased to exist as such, and were replaced by other unknown lines. According to Professor Lockyer, these lines represent the elements split into simpler forms by the increased heat at the sun-spot maximum.

There has been a good deal of controversy over Professor Lockyer's theory. The following is Miss Clerke's estimate—

"It only asks us to believe that processes which we know to take place on the Earth under certain conditions are carried further in the Sun, where the conditions are, it may be presumed, vastly exalted. We find that the bodies which we call 'compound' split asunder at fixed degrees of heat *within* the range of our resources. Why should we hesitate to admit that the bodies we call 'simple' do likewise at degrees of heat *without* the range of resources? The term 'element' simply expresses terrestrial incapability of reduction. That, in celestial laboratories, the means and their effect, here absent, should be present, would be an inference challenging, in itself, no expression of incredulity."

Perhaps Professor Lockyer's name is best known through his theory of the evolution of the stars. He communicated to the Royal Society on November 17, 1887, the first of a series of papers containing the "Meteoritic Hypothesis" of stellar evolution, which was presented to the world in 1890 in his elaborate and epoch-making volume, "The Meteoritic Hypothesis; A Statement of the Results of a Spectroscopic Inquiry into the Origin of Cosmical Systems," and was further developed in "The Sun's Place in Nature" (1897). This theory—which, it should be stated, was originally suggested by the late Professor Tait, and the late Mr. Proctor—is called by Dr. Henry Smith Williams, in his "Story of Nineteenth Century Science," "perhaps the most comprehensive cosmogonic guess that has ever been attempted." Professor Lockyer, in his work, claims that his views are merely extensions of the ideas of Professor Schiaparelli regarding the "local concentration of celestial matter." The fundamental view of the meteoritic hypothesis is thus expressed by Professor Lockyer—"All self-luminous bodies in the celestial space are composed either of swarms of meteorites or of masses of meteoric vapour produced by heat. The heat is brought about by the condensation of meteor swarms due to gravity, the vapour being finally condensed into a solid globe."

The stars were divided by Professor Lockyer into seven groups, according to temperature. The nebulæ, regarded as

aggregations of meteors, were supposed to be the coolest celestial objects, the temperature rising through gaseous stars, red stars of Secchi's third type (such as *Betelgeux*), and a division of solar stars to the Sirian type, regarded by Professor Lockyer as the hottest stars; the temperature falling through a second division of the solar type, and the red stars of Secchi's fourth type, to dark stars. Professor Lockyer then proceeds to say that "stars, the temperatures of which are increasing, do not resemble the Sun, but consist chiefly of discrete meteoritic particles, just as comets do in Schiaparelli's hypothesis." Professor Lockyer accounts for variable stars of long period, such as *Mira* Ceti, by the theory that these stars are in the condition of meteoric swarms revolving round each other. The revolutions of lesser swarms round greater must, as a consequence, produce collisions which periodically raise great numbers of meteors to incandescence. According to this view, variables are not, strictly speaking, stars, but swarms of meteors. It must be admitted that this part of the theory is somewhat artificial. The nebulæ are regarded by Professor Lockyer as vast aggregations of meteorites in rapid motion coming into constant collision. The velocity is so great that heat and light are produced at each collision. Binary stars are supposed to have had their origin in double nebulæ. Temporary stars, "whether seen in connection with nebulæ or not, are produced by the clash of meteor swarms. . . . In recorded time there has been no such thing as a 'world on fire,' or the collision of masses of matter as large as the Earth, to say nothing of masses as large as the Sun; but the indicated distribution of meteorites throughout space indicates that such collisions form an integral part of the economy of nature."

Such, in brief outline, is Professor Lockyer's famous hypothesis of the evolution of the Universe. It is an ingenious theory, but it lacks simplicity, and although it has explained some seeming mysteries, it has not gained universal acceptance. One of its fundamental points, that of the evolutionary order of the stars, has been disputed. So high an authority as Dr. Vogel considers stars of Secchi's third type to be orbs

hastening on the road to extinction; and Dr. Vogel's evolution theory is accepted by Dr. Dunér, Dr. Scheiner, Sir William Huggins, Professor E. C. Pickering, and Mr. Gore. On the whole, it must be admitted that the Meteoritic Hypothesis has many drawbacks, and in many points lacks the simplicity of the original Nebular theory. Professor Newcomb, indeed, says of the Meteoritic Hypothesis—"The objections to this theory seem insuperable. A velocity so great at such a distance from the centre of the nebulæ would be incompatible with the extreme tenuity of these objects. Every time that two meteors came into collision they would lose velocity, and therefore, if the mass was sufficient to hold them from flying through space, would rapidly fall towards a common centre. . . . The meteors which fall on the Earth are mostly of iron, and were the theory true, numerous lines of iron should be conspicuous in the spectrum."

Another fundamental objection to the Meteoritic Hypothesis has been raised. Professor Lockyer, in 1887, came to the conclusion that the chief line in the spectrum of the Orion nebula coincides with the remnant of the fluting of magnesium, which is conspicuous in the spectra of comets and meteors. Now, if it could be proved that the line was really due to magnesium, the Meteoritic Hypothesis would have much in its favour. Professor Lockyer concluded that the line actually coincides with the fluting of magnesium, but Sir William Huggins and the late Professor Keeler, with more powerful instruments, found that such was not the case. Mr. Gore concludes that "the weight of evidence is against the truth of the Meteoritic Hypothesis"; and this is the opinion of the majority of modern astronomers. Nevertheless, although Professor Lockyer's theory remains unconfirmed, it has done service to science by keeping alive the speculative side of astronomy. In this case, as in that of Newton's theory of light, Herschel's idea of the constitution of the Sun, and Mädler's hypothesis of the construction of the heavens, it is interesting to have the speculations of great men, even though they should be overthrown by further investigation.

Professor Lockyer has directed several expeditions to foreign countries for observation of total solar-eclipses. He was chief of the English Government expedition which was sent to observe the eclipse of 1870 in Sicily. During his journey in the *Psyche*, he was shipwrecked, and had a glimpse of the eclipse for only a second and a half. On December 12, 1871, he observed the total eclipse of that year in India. He employed for observation during this eclipse, a "slitless" spectroscope, similar to that used by Fraunhofer. He observed in company with the Italian astronomer, the late Professor Respighi, and some valuable observations were made. In 1886, Professor Lockyer directed an eclipse expedition to the West Indies. The place of observation was known as Green Island, and the eclipse took place in the middle of the rainy season. He says of his observations—"The only thing I saw was a cloud, which formed and began to obscure the Sun soon after the first contact, and grew till after totality." Professor Tacchini, who accompanied the expedition, made some remarkable observations. In 1896, Professor Lockyer went to Norway for the purpose of observing the total eclipse on August 9 of that year. In his admirable and very readable volume, "Recent and Coming Eclipses" (1897), he gives a very interesting description. The expedition was perhaps the greatest ever set up to observe an eclipse. The weather was very promising at first, but on the afternoon of August 8 the sky clouded over, and so it remained until after the eclipse. But Professor Lockyer was more successful in India on January 22, 1898, and in Spain on May 28, 1900.

A number of honours have been conferred on the distinguished astronomer. In 1871, he was Rede Lecturer at Cambridge. He was Bakerian Lecturer to the Royal Society in 1874, and received the Rumford Medal in the same year. Professor Lockyer was created C.B. in 1894, and Knight Commander of the Bath in June 1897, on the occasion of Queen Victoria's Diamond Jubilee. He is a foreign member of many scientific societies on the Continent, and is a Knight of the Brazilian Order of the Rose. He presided over the

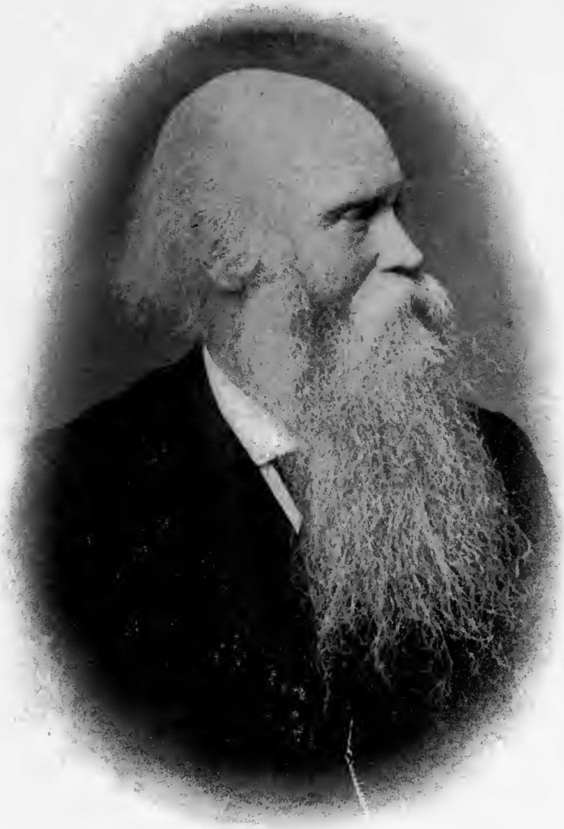
British Association at its meeting at Southport in September 1903; but, instead of devoting his address to his own science, as Sir William Huggins did, he chose as the subject of his address, "The Influence of Brain Power on History."

One of Sir Norman Lockyer's most recent contributions to science has been to establish the connection between sun-spots and earthquakes. In June 1902 he remarked—"Because the terrible catastrophes in Martinique and St. Vincent occurred at a well-defined sun-spot minimum, I was led to inquire whether similar coincidences were to be traced in the past. . . . I find it beyond question that the most disastrous volcanic eruptions and earthquakes generally occur, like the rain pulses in India, round the dates of the sun-spot maximum and minimum. . . . In 1867, Mauna Loa, South America, Formosa, Vesuvius, were among the regions involved: in the West Indies it was the turn of St. Thomas. The many announcements of earthquakes in the present year (1902) before the catastrophe of St. Pierre will be in the recollection of everybody. In the maximum of 1871-72, to name only West Indian stations, Martinique first, and then St. Vincent, followed suit; in the next maximum in 1883 came Krakatoa. In Tokio, in a country where the most perfect seismological observatories exist, we find that at times near both sun-spot maxima and minima the greatest number of disturbances have been recorded."

Sir Norman Lockyer is a prolific writer. His first book was "Elementary Lessons in Astronomy," which appeared in 1870. This was followed by "Contributions to Solar Physics" (1873), "The Spectroscope and its Applications" (1873), and "Primer of Astronomy" (1874). His "Studies in Spectrum Analysis," which was published in 1878, is almost entirely devoted to chemistry. This volume was followed by "Star-Gazing, Past and Present" (1878), written in conjunction with Mr. G. M. Seabroke, of Rugby. Sir Norman's other works are "The Chemistry of the Sun" (1887), "The Meteoritic Hypothesis" (1890), "The Dawn of Astronomy" (1894), "The Sun's Place in Nature" (1897), "Recent and Coming Eclipses," a more popular work,

which appeared in the same year, and "Inorganic Evolution," (1900). Sir Norman Lockyer, however, like Professor Newcomb, does not confine his attention purely to astronomy, for he published some years ago, a book on golf. At the Solar Physics Observatory, he is ably assisted by his son, Dr. W. J. Lockyer, who has accompanied him on eclipse expeditions, and who has found time for original astronomical investigations. Dr. Lockyer is one of the rising astronomers of England, and his work already forms a worthy sequel to that of his illustrious father.

Sir Norman Lockyer's labours have gained for him an enduring reputation. He ranks as one of the founders of spectroscopy, and his work in solar astronomy places him among the most distinguished observers of the Sun. His investigations and speculations place him in the front rank of modern astronomers.



Ralph Copeland.

Ralph Copeland.

AMONG the modern astronomers who, by observation, have advanced our knowledge of the heavens, the name of Professor Ralph Copeland, Astronomer-Royal for Scotland, holds a conspicuous place. Like Sir William Huggins and Sir Norman Lockyer, the greatest of his services have been to spectroscopic astronomy. Like several other eminent astronomers, also, his life presents a striking illustration of perseverance under difficulties. Dr. Copeland is a self-made man.

Born on September 3, 1837, near Woodplumpton, in Lancashire, Ralph Copeland received his early education from a weaver, and afterwards proceeded to the Grammar School of Kirkham. After completing his school education at Kirkham and other establishments, he emigrated to Australia, and spent several years as a shepherd at the foot of the Australian Alps. In the vast solitudes of the Australian plains, his attention was drawn to the wonders of the heavens. He sent home to England for a small telescope, with which he began to study the southern skies. Meanwhile, he was attracted to the gold-diggings in the Omeo district; after spending some time there, he determined to return to his native country. On his return journey, in which he sailed round Cape Horn, he tested the astronomical knowledge which he previously acquired, and read with much interest Sir John Herschel's "Outlines of Astronomy." On the voyage he was the first to observe Donati's great comet of 1858. After his return to England, Mr. Copeland became an apprentice to a firm of locomotive

engineers. Some of those in the employment were interested in mathematics and astronomy, and in conjunction with them, Mr. Copeland succeeded in founding a small observatory, and, after procuring a 5-inch refractor, began a series of regular observations of the celestial bodies, which, however, were not destined to be continued for long. In 1864, trade in Lancashire was greatly depressed by the cotton famine, the result of the Civil War in the United States, and Mr. Copeland, acting on the advice of Dr. Schnackenberg, his former teacher, decided to go to Germany to study astronomy in some of the German universities. He therefore spent eight months in a small village in Hesse for the study of the German language, and early in 1865, he entered the University of Göttingen for the systematic study of astronomy. He was appointed volunteer assistant at the Göttingen Observatory in 1867, and, along with Carl Börgen, afterwards director of the Observatory of Wilhelmshaven, he fixed the positions of over three thousand stars lying immediately south of the celestial equator in a belt of two degrees. These observations formed the basis of the first Göttingen star catalogue, which was published in 1869.

After taking his degree of Ph.D. at Göttingen, Dr. Copeland along with Herr Börgen, became a member of the German Arctic expedition which was sent to explore the coast of East Greenland. The vessels sent on the expedition were the *Germania* and *Hansa*, the latter of which was lost in the ice. On the arrival of the expedition in Greenland, two small observatories were built, and there amid the snow and ice the scientific staff recorded meteorological observations hourly. Much attention was also given to terrestrial magnetism and the aurora borealis. Two volumes were afterwards published containing these observations. Dr. Copeland, as well as the other explorers, paid much attention to natural history, and, on his return to Germany he received, along with the captains of the expedition and a few scientific members, the Order of the Red Eagle from the Emperor William I. He was also elected an honorary member of the Natural History Society of Bremen.

Soon after his return from the Arctic regions, Dr. Copeland left Germany and was appointed astronomical assistant to the younger Earl of Rosse, at Birr Castle, Ireland, where the two great reflectors of three and six feet aperture respectively had been constructed by the previous Earl. For three years and a half Dr. Copeland retained this position, and was chiefly employed in measuring with the 3-foot reflector the radiant heat of the Moon, observing the nebulæ and other celestial objects with the great 6-foot instrument. In 1874, he received the appointment of assistant astronomer to Dr.—now Sir Robert—Ball at the Dunsink Observatory in Dublin. Before entering on his duties there, however, he became a member of the expedition of Lord Lindsay, afterwards Earl of Crawford and Balcarres, to observe the transit of Venus at the island of Mauritius, in December 1874. The observations of the transit, unfortunately, were not favoured with good weather. On the outward voyage the vessel called at a small uninhabited island in the South Atlantic, named Trindada, and there Dr. Copeland discovered a great tree fern now known as *Cyathea Copelandi.*

After spending two years in Dublin, Dr. Copeland was appointed in 1876 astronomer to Lord Lindsay at the latter's private observatory at Dunecht, in Aberdeenshire. In 1882 he was again chosen to observe the second transit of Venus visible in the nineteenth century. The Government Committee appointed Dr. Copeland to the station at Jamaica, and fortunately the transit was attended by good weather. In 1883 he visited the Andes of Peru and Bolivia in order to test the advantages of observations made at a high level, and spent six months at altitudes of from 10,000 to about 15,000 feet. While on this expedition he discovered five gaseous Wolf-Rayet stars. He also examined and mapped the spectrum of the famous gaseous star γ Argûs. He says—"An intensely bright line in the blue, and the gorgeous group of three bright lines in the yellow and orange render the spectrum incomparably the most brilliant and striking in the whole heavens."

Dr. Copeland's cometary researches occupied much of his time while employed at Dunecht. He observed and investigated

the great comet of 1880, discovered by the late Dr. Gould at Cordoba. Dr. Copeland made an investigation of its path, independently of Gould and Hind, and was struck with the similarity between its orbit and that of the great comet of 1843. In conjunction with Dr. Lohse, Dr. Copeland made several important spectroscopic observations on Brorsen's comet, at its appearance in 1879, and on the comet of 1881. He gave much attention to the great comet of September 1882. He was the first to observe its spectrum, which he did on September 18, identifying six brilliant rays with prominent iron-lines. Along with Dr. Lohse, he noticed that all the lines showed traces of displacement, which, interpreted by Doppler's principle, proved the comet to be receding from the Earth with a velocity of from 37 to 46 miles a second. Dr. Copeland's observations were the means of adding much to our knowledge of cometary constitution. He spectroscopically observed both variable and temporary stars. The variable U Orionis, discovered in December 1885 by Mr. Gore, was announced by Dr. Copeland to have "a very beautiful banded spectrum of the third type, seven dark bands being readily distinguished with the prism." On September 30, 1886, Dr. Copeland measured in the spectrum of the new star in the Andromeda nebula, three bright bands. In 1880 the eminent astronomer discovered a nebula spectroscopically by the method employed by Professor Pickering about the same time. He recognised it not by means of the telescope, but by its gaseous spectrum; in 1884 he detected by the same method another nebula, in Aquila, which had previously been regarded as a star.

A very remarkable addition to our knowledge of the nebulæ was made by Dr. Copeland at Dunecht in 1886. He ascertained by means of the spectroscope the existence of helium in the Great Nebula in Orion, eighteen years after it was discovered by Sir Norman Lockyer in the Sun, but nine years before it was recognised in our own planet, and four years before Dr. Scheiner's observations on the helium-line in the Orion stars. It has indeed been said that the helium-ray suggests that the matter composing the nebula is in a high state of electrical excitement. Helium

is now recognised as universal—indeed as one of the original elements, which is conspicuous in the spectra of nebulæ and stars of Secchi's first type, but has almost disappeared from stars of the second and third types. The detection of helium in the Orion nebula was perhaps Dr. Copeland's greatest discovery.

In 1887 Dr. Copeland was appointed by Lord Crawford and Balcarres to start on an expedition to Central Russia to observe the total eclipse of the Sun visible in August of that year; unfavourable weather, however, frustrated the chief intention of the expedition. Dr. Copeland was for some time joint-editor of the astronomical periodical *Copernicus*, which he edited in conjunction with Dr. J. L. E. Dreyer. At the meeting of the British Association at Cardiff in 1891 Dr. Copeland exhibited a model of the Moon illustrating his theory of the bright streaks radiating from the crater Tycho. He suggested that the material constituting the surface of the streaks is composed of a number of more or less spherical globules; these streaks probably representing part of the surface covered with small spherical cavities or with minute transparent spheres.

Early in 1889, Dr. Copeland became third Astronomer-Royal of Scotland in succession to the late Professor C. Piazzi Smyth, who succeeded Thomas Henderson in 1844. He was also appointed Professor of Astronomy in the University of Edinburgh. The post of Astronomer-Royal, of course, carried with it that of director of the Calton Hill Observatory. At this time arrangements were being made for the erection of a new Royal Observatory on the summit of Blackford Hill, and the first seven years of Professor Copeland's residence in Edinburgh were occupied in planning and superintending the erection of the Observatory, which was equipped with the instruments belonging to Lord Crawford and Balcarres. Dr. Copeland accordingly left the Calton Hill Observatory to take up his duties as director of that on Blackford Hill, which began activity in the spring of 1896. His successor at the Calton Hill Observatory was Mr. William Peck, F.R.A.S., Astronomer to the City of Edinburgh, who has already done much for the

popularising of the science, and is well known for his work in practical astronomy.

Since 1896 much valuable work has been done at the Blackford Hill Observatory in the departments of spectroscopic astronomy and celestial photography, and in the former department a leading part has been played by Dr. Halm, Dr. Copeland's eminent assistant. Professor Copeland has taken a special interest in observations of the two temporary stars, discovered by Dr. Thomas D. Anderson respectively in January, 1892 and on February 22, 1901. Professor Copeland has directed three solar eclipse expeditions since the opening of the new observatory. The first of these, visible on August 9, 1896, in Norway, was unsuccessful, but the second, visible in India, January 22, 1898, was attended by favourable weather. To observe the eclipse of May 28, 1900, Dr. Copeland and Mr. Heath, his able assistant, visited Spain and secured a valuable series of photographs.

It will be seen from this brief sketch of Professor Copeland's life and work that he has had a wide, varied, and successful astronomical career, and has added much to our knowledge of the heavens. His spectroscopic investigations and discoveries gain for him a high position in nineteenth-century astronomy. His life is a brilliant example to all who take an interest in the great science.

Pietro Tacchini.

(Photo. by Baldelli, Reale & Montesi, Rome.)

Pietro Tacchini.

It is remarkable that there are living at present in Italy three distinguished astronomers, pursuing different branches of the science, so that the work of the one is supplementary to that of the others. Telescopic and statistical astronomy, the older branch, is represented by Professor Schiaparelli and Professor Celoria, of Milan; while the new astronomy has been successfully pursued for many years by Professor Tacchini, director of the Observatory of the Collegio Romano, whose life and work forms the subject of this chapter.

Pietro Tacchini was born at Modena, in the Emilia, on March 21, 1838. At the University of Modena he studied mathematics, and took his degree when nineteen years of age. In 1858 he pursued studies in astronomy at the Observatory of Padua under the direction of the distinguished astronomer Santini. The following year, at the age of twenty-one, he was appointed by the Italian Government director of the Observatory of Modena, which position he held until 1863, when he became astronomer in the Observatory at Palermo. At Palermo, he commenced his observations on the Sun, both direct and by means of the spectroscope, in which branch of research he has gained his reputation. He made many important observations of the metallic injections in the photosphere, and in 1870 led the expedition in Sicily which observed the total solar eclipse visible on December 22 of that year. In 1872 he founded the Spectroscopic Society of Italy, to which many of his memoirs and papers have been communicated.

At this time a magnificent field of solar observation had been opened by the discovery of Janssen and Lockyer that the solar prominences could be observed in daylight. The observations made at Rome by Secchi and Respighi gave a new impulse to the study in Italy. Professor Tacchini early recognised the necessity of making systematic observations on the solar prominences, which he commenced in conjunction with Secchi and Lorenzoni. The late Professor Piazzi Smyth, Astronomer-Royal for Scotland, who, in March 1872, went to Palermo for the purpose of observing the Zodiacal Light in a clear atmosphere by means of the spectroscope, remarks that he visited the Palermo Observatory—at that time directed by the late Professor Cacciatore—where he "profited in solar spectroscopy by seeing Signor Tacchini's masterly handling of the 20-prismed instrument attached to the Palermitan equatorial, comparing his daily drawings of red prominences with those furnished by Father Secchi at Rome and Signor Lorenzoni at Padua." Spectroscopic observations on the Zodiacal Light were conducted for some evenings by Piazzi Smyth, Tacchini, Cacciatore, and Riccò, who never found in its spectrum the line of the aurora, as some observers had reported.

As early as 1873, Signor Tacchini's observations had led him to important results. In May of that year, in a remarkable note published in the memoirs of the Spectroscopic Society of Italy, he discussed the connection between the solar prominences and the terrestrial aurora borealis. In the latter phenomena, he considered that "taking into account their form, their variability and their movement, we should recognise the action of an agent analagous to electricity, and that in consequence their presence should be considered as indicative of a particular electric or auroral state of the Sun." From his observations of the prominences, Signor Tacchini was enabled to predict the appearance of several auroras, which, but for the prediction, would not have been seen at Palermo—thus proving the close connection between the auroras and the state of the Sun. Professor Tacchini pointed out "that

the terrestrial auroras are more in relation with the protuberances than with the solar spots."

In 1874 Professor Tacchini led the Italian expedition which observed the transit of Venus from Bengal. He carefully examined the solar spectrum at the point occupied by the planet, and from his observations he inferred the existence of an atmosphere surrounding Venus which he concluded to be "probably of the same nature as ours." At Palermo, Professor Tacchini observed sun-spots, and he also made observations on the stars with the meridian circle, while some of his attention was given to meteorology. In 1879 he organised, at the request of the Italian Government, the Meteorological and Geodynamical Institute of Rome, of which he became director.

In 1879 Professor Tacchini was appointed director of the Observatory of the Collegio Romano, which position had been vacant since the lamented death, on February 26, 1878, of the great astronomer Secchi. Since his appointment at Rome, he has devoted much attention to the observation of sun-spots, and spectroscopic observations of prominences, comets, and other celestial phenomena. On October 14, 1883, he observed one of the most gigantic sun-spots ever recorded, no less than seven times the size of the Earth.

Professor Tacchini observed the total eclipse of 1882 in Egypt. In 1883 he accompanied M. Janssen to Caroline Island, a coral reef in the Pacific, for the observation of the total eclipse of May 6 of that year. During the eclipse, he made the important discovery of *white* prominences about a hundred thousand miles high. After the end of the eclipse he attempted to view the prominences spectroscopically, but failed. They gave a continuous spectrum, undistinguished either by hydrogen or helium. The existence of these "white prominences" was confirmed by Professor Tacchini's further observations made in 1886. On the occasion of the total eclipse of August 29, 1886, he was invited to accompany the expedition led by Professor Lockyer to Grenada, in the West Indies. He observed a gigantic

white prominence, 150,000 miles in height, which gave a brilliant continuous spectrum, with bright calcium lines, but none representative of hydrogen. The Italian astronomer noticed that during the eclipse it was framed by an arch of coronal light. At the same eclipse, by a comparison of the forms and sizes of prominences both during the eclipse and after the end of totality, he demonstrated the remarkable fact that ordinarily the spectroscope reveals only the cores, glowing and vaporous, of these objects. The upper parts of the prominences, visible only during eclipses, give a faint continuous spectrum, a fact which strongly suggests that these are composed of cooler material than the central portions. The existence of purely white prominences is, therefore, explained by the fact that these objects do not possess any gaseous cores, which distinguish the ordinary solar protuberances.

Signor Tacchini has done for the observation of solar prominences what Schwabe did for observation of the spots. By daily observations at Rome and Palermo, carried out with that determination and persistence which distinguishes the great men of science, he has brought to light many new facts, while his observations of individual objects are of surpassing interest. On January 30, 1885, he measured at Rome one of the greatest prominences which has yet been observed. The height of this remarkable object was no less than 142,000 miles—eighteen times the diameter of the Earth. Professor Tacchini made a drawing of the great protuberance, which is reproduced in M. Flammarion's "Popular Astronomy." A diagram of the Earth on the same scale as the mighty sunflame is given in the same work, and impresses the reader with the extraordinary vastness of the great solar eruptions.

In 1889 Professor Tacchini published certain results as to the distribution of solar prominences. He was the first astronomer to notice that the coronal streamers originate in regions where the prominences are most numerous. At the time of sun-spot maximum, prominences are spread all over the Sun, and the corona distributed uniformly; at the

minimum, on the other hand, the prominences are withdrawn from the polar regions, and at the same time these regions become devoid of coronal streamers. Miss Clerke, in her "History of Astronomy," says of Professor Tacchini's observations: "The results are somewhat complicated, but may be stated broadly as follows:—The district of greatest prominence-frequency covers and overlaps by several degrees that of greatest spot-frequency. There is a visible tendency to a second pair of maxima near the poles, which are themselves, like the equator, regions of minimum occurrence. Distribution of time is governed by the spot-cycle, but the maximum lasts longer for prominences than for spots."

Professor Tacchini was the first astronomer to regard many of the phenomena of the chromosphere and the solar atmosphere as products of electrical action on the great luminary. It is becoming more and more apparent that electricity has much to do with the phenomena of the Sun. As already mentioned, a remarkable fact pointed out by Professor Tacchini is the connection between the solar protuberances and the varying intensity of the aurora borealis, which, together with the fact of the correspondence between sun-spots and terrestrial magnetism, gives further support to the idea of an electrical connection between the Sun and the Earth.

The following estimate of the work of Professor Tacchini is from the Report of the Royal Society of London, in November 1888, when he received the Rumford Medal:—"The Rumford Medal has been awarded to Professor Pietro Tacchini for important and long-continued investigations, which have largely advanced our knowledge of the physics of the Sun. Professor Tacchini occupies a foremost place among those who have paid special attention to the physics of the Sun. Since 1870 he has unceasingly observed, first at Palermo and afterwards at Rome, the solar prominences. The information at our disposal at the present time, both as regards their distribution, their spectra, and the changes which take place in them, and their connection with other solar phenomena, rests to a large extent upon his individual efforts. His memoirs on this

subject are very numerous. He has been engaged in the observation of four total solar eclipses, and from some of the phenomena therein observed has drawn the important conclusion that many of the so-called prominences are really descending currents."

Professor Tacchini's visual observations on Venus were conducted at the Observatory of the Collegio Romano in 1895. As is well known, controversy has for long raged regarding the rotation period of the planet; while the observations of Schröter, Di Vico—one of Professor Tacchini's predecessors at the Collegio Romano—and others, indicated a rotation period of twenty-four hours, Professor Schiaparelli in 1877-1889, and again in 1895, found a period of 225 days, equal to the period of revolution. Professor Tacchini commenced his observations on the planet in the summer of 1895 with the object of determining the rotation period. His first observations led to a confirmation of Professor Schiaparelli's rotation period, and a second series gave a more decisive result. For instance, on November 28, 1895, the Roman astronomer observed Venus continously for over five hours, and the same features were constantly seen on the illuminated portion of the disc, a conclusion which is quite sufficient to negative the idea of rotation in a short period, and is strongly confirmative of Professor Schiaparelli's results. Professor Tacchini's conclusions were confirmed by observations made by Signor Mascari at Catania, Signor Cerulli at Teramo, the late M. Perrotin at Nice, and, above all, by Mr. Percival Lowell at Flagstaff, Arizona.

In 1895 Professor Tacchini founded the Seismological Society of Italy, while he is also the founder of the Astronomical Observatory at Mount Etna and the Astrophysical Observatory of Catania, at both of which institutions observations of great value have been made by Professor Riccò and Signor Mascari. In 1900 Professor Tacchini observed the eclipse of May 28 of that year in Algeria. Professor Tacchini has received numerous honours. For his solar observations he was awarded in 1888 the Rumford Medal of the Royal Society

of London, and in 1892 the Janssen Gold Medal from the French Academy of Sciences. He is a member of many academies and scientific societies, both in Italy and elsewhere; while he has been the recipient of many Orders, both Italian and foreign.

The work accomplished by this illustrious Italian astronomer, is sufficient to give him an enduring place in the history of astronomy. He is one of the most distinguished solar observers, and by his careful and persistent study of the prominences has brought to light many remarkable facts concerning the Sun, the most important being the connection between the distribution of the prominences and the form of the corona. Professor Tacchini's observations are a brilliant example of indefatigable perseverance, scrupulous care, and boundless enthusiasm in the study of the orb of day.

Sherburne Wesley Burnham.

THE subject of our present chapter, Professor S. W. Burnham, of the Yerkes Observatory, occupies not only a very high position among the astronomers of the United States, but is, with the single exception of the venerable Otto Struve, the greatest living observer of double stars. Professor Burnham, like so many of the great modern astronomers, is a self-made man. By his untiring exertions, he has placed himself in a position second to none among American students of the heavens.

Born at Thetford, Vermont, on December 12, 1838, Sherburne Wesley Burnham received his education in the Academy of his native town. He early adopted the profession of stenographer, or shorthand reporter to the Court. While stationed in New Orleans during the Civil War he procured a book on astronomy, Burrit's "Geography of the Heavens," which he studied carefully, finding that it contained charts of the stellar heavens, with the help of which he became acquainted with the various constellations. Soon after this, during a visit to London, he bought a small cheap telescope, and on going to Chicago some time later, became the possessor of a $3\frac{3}{4}$-inch telescope, which, in his own words, "was just good enough to be of some use, and poor enough, so far as its optical power was concerned, to make something better more desirable than ever."

At this time, about 1866, Mr. Burnham was also interested in microscopy, which he studied simultaneously with astronomy.

He perused Webb's "Celestial Objects for Common Telescopes,"—of which he speaks in the highest terms—as well as volumes on mathematical astronomy. In 1869 he accidentally met Alvan Clark, the well-known optician, on his return from Iowa, where he had observed the total solar eclipse of that year. Inquiring of him regarding a small equatorial telescope, the result was the construction of a 6-inch telescope for Mr. Burnham. Previous to this, he had for several years, while observing with the smaller telescope, devoted much attention to double stars, and this work was continued with the larger instrument. The following description of his first observations, from the pen of an American writer, gives a clear description of the difficulties he encountered, and how he overcame them:—"The problem still remained of having his telescope permanently mounted. Procuring a large piece of timber, he sunk it deep in the ground in the back yard of his little house in Vincennes Avenue, near Ellis Park. Around this timber he built what his friends used laughingly to call a 'cheese box,' on the top of which he placed a dome that could be turned around easily at will. Most of the work he did with his own hands, and it was with this little telescope, rudely mounted, that this modest, quiet shorthand reporter made his first important discoveries of double stars, discoveries which in a few years attracted the attention and commanded the admiration of the leading scientific men in Europe."

Mr. Burnham's little observatory was fitted with neither sidereal clock nor transit instrument, and the telescope lacked even the clockwork motion to follow the apparent diurnal rotation of the heavens; but he overcame this difficulty. We learn from the same authority that he had a substitute, "simply a long vertical tube filled with sand, with an orifice at the bottom through which the sand could escape, after the manner of an old-fashioned hour-glass. A lead plunger, following the descent of the sand through the tube, gave the proper motion to the telescope, and held it as firmly on a star as could be done by clockwork." In this little observatory Mr. Burnham

made, in 1871, his first discoveries of double stars. By 1873 he had found no fewer than eighty-one new pairs, and sent a list of these to the *Monthly Notices* of the Royal Astronomical Society. Meanwhile, he had become acquainted with the Rev. T. W. Webb, author of "Celestial Objects," who was so much impressed with his work that in 1874 he proposed Mr. Burnham as a Fellow of the Royal Astronomical Society, and secured his election.

Meanwhile, Mr. Burnham, while discovering new double stars, found the list given in Webb's volume far from exhaustive. During his surveys of the heavens, double stars were found which were not given by Webb; but before it could be ascertained whether they were new pairs or not it was necessary to examine other catalogues. At the Dearborn Observatory, Chicago, the Naval Observatory, Washington, and the Dartmouth College Observatory, he made manuscript copies of the catalogues of Wilhelm and Otto Struve, of South, Sir John Herschel, Mädler, and other astronomers. Mr. Burnham now constructed a manuscript catalogue of all the double stars known to exist, arranged in order of Right Ascension. "With this at hand," he says, "it was but a moment's work at the telescope to identify any known object, and to decide at once whether or not an object thus found was really a new pair." A second catalogue of double stars discovered by Mr. Burnham was published in the *Monthly Notices* in May 1873. This contained twenty-four new pairs. A third catalogue, embracing seventy-five new pairs, was published in December of the same year, and this was followed by other catalogues in June and December 1874. These discoveries created much interest in double-star astronomy, although the belief still persisted that the field of discovery had been worked out by the Herschels and the Struves. Writing to Mr. Burnham in 1873, Mr. Webb remarked: "It will hardly be possible for you to go on for any great length of time as you have begun, because the number of such objects is not interminable, and every fresh discovery is one less to be made." Nevertheless, Mr. Burnham remarked in 1899 that "the prospect of future

discoveries is as promising and encouraging as when the first star was found with the 6-inch telescope."

Among the astronomer's early discoveries must be mentioned β Delphini, which he discovered in 1873, and which completes a revolution in about twenty-six years. A minute companion to α Ursæ Majoris was also discovered. Meanwhile, the astronomer's discoveries attracted all-round attention. Professor Young permitted him to use the Dartmouth telescope, and with it he discovered twenty-four new double stars. Although Mr. Burnham's 6-inch telescope was one of the finest productions of Alvan Clark, it lacked a micrometer, which is essential to the exact measurement of double stars. Mr. Burnham, therefore, could not measure the pairs which he discovered. Accordingly, he wrote to the famous astronomer, Dembowski of Milan, requesting him to undertake the measurement, which he did "in the most painstaking and thorough manner" as Mr. Burnham remarks; while a friendship was commenced which lasted until the death of Dembowski in 1881.

Mr. Burnham was allowed the use of the 18½-inch telescope of the Dearborn Observatory from 1876 onwards. Indeed, for a short time he filled the office of director of the Observatory. He also observed at the Naval Observatory, Washington, and discovered fourteen new pairs. By 1879 he had discovered no fewer than 733 double stars with the telescope mentioned. Some of these pairs proved of great interest. In 1871, while examining with the 6-inch telescope *Rigel* and its companion, he suspected an elongation of the latter, which he confirmed in 1878 by observations at the Dearborn Observatory. These observations were continued on Mount Hamilton with the 6-inch, and the previous results confirmed. But in 1880 and 1882, with the 18-inch telescope at Chicago, the star appeared perfectly round, and the 36-inch of the Lick Observatory showed it as "certainly single." In regard to this, Mr. Burnham wrote: "One of two conclusions seems obvious. Either this star is not double at all, the elongation supposed to be seen on the different occasions being due to atmospheric or

other causes; or, if double, it must be moving with great rapidity." In 1899, however, measures by Professor Aitken proved the duplicity of the star. "It is equally certain," says Professor Burnham, "that the period will be very short, perhaps shorter than that of any known system." It may be remarked here that Mr. Burnham has never yet been deceived in his double-star observations by any illusory stars.

In 1875 Mr. Burnham, using his 6-inch telescope, discovered the star 82 Ceti to be a very close double. It turned out to be a very short binary, with a period of about sixteen years. In the same year, and with the same instrument, he discovered the duplicity of 9 Argûs, which also appears to be a short binary. An orbit computed by him in 1892 gave a period of twenty-three years. With the 18½-inch Dearborn telescope, in 1877, he detected the nearest companion to *Aldebaran*, which shares the proper motion of the brilliant star. In the following year he discovered the duplicity of 85 Pegasi, which he considers to be "one of the most important and most interesting of the known binary systems. The shortness of its period, the rapid movement in space of both components, the relative nearness of this system to our own, and the extreme inequality in magnitude and closeness of the stars all combine to give this a leading place among binary stars." On the night of the star's detection four other double stars were also found. According to an orbit computed by Mr. Burnham, the period of 85 Pegasi is abont twenty-five years. In 1879, when using the Dearborn telescope, he discovered the duplicity of 20 Persei, which has a period of about twenty-seven years. In 1880 another very important binary star was found by the distinguished astronomer, which has been followed through one and a half revolutions. The period of this star, κ Pegasi, is, according to Mr. Burnham's calculations, only eleven years. He remarks that "future investigations probably will not materially change the period, but may improve some of the other elements of the orbit."

In 1879, on the selection of the site of the Lick Observatory, it was advised that an experienced astronomer should visit

Mount Hamilton to test the climatic conditions. Professor Newcomb recommended Mr. Burnham, and in August 1879 the astronomer arrived at Mount Hamilton, Professor Newcomb following a month later. Mr. Burnham, who used his 6-inch telescope, discovered a number of new double stars on his visit, and reported favourably on the atmospheric conditions. In 1881 he again visited Mount Hamilton to observe the transit of Mercury, and made further double-star discoveries. On his return to Chicago he pursued his investigations, and continued to publish lists of new double stars, which appeared from time to time in various periodicals. Mr. Burnham's reputation had become so high that in 1888 he was appointed chief assistant at the Lick Observatory. With the great 36-inch refractor, during the next four years, he detected no fewer than 198 new double stars. In 1889 he discovered a faint companion to the pair μ Draconis. With the 12-inch refractor of the same Observatory, he discovered 56 pairs.

At the Lick Observatory, Mr. Burnham gave attention to other branches of astronomy besides double stars. He observed the total solar eclipse of December 22, 1889, from Cayenne, and secured some valuable photographs. In conjunction with Professor Barnard he attempted to measure the parallax of *Nova* Aurigæ, but was unsuccessful on account of its great distance. In 1891 some careful measurements were made of the positions of planetary nebulæ. He noticed the possession by each planetary nebula of a sharp star-like nucleus, by means of which its position could be fixed with reference to the neighbouring stars as accurately as that of a star. The objects which he observed cannot shift their positions by even a fraction of a second of arc without the change being perceived. Mr. Burnham's researches on nebulæ, undertaken at the Lick Observatory, have constituted him an authority on that branch of astronomy. He studied attentively planetary nebulæ, double nebulæ, nebulous stars and variable nebulæ.

In 1892, on receiving a legal appointment at Chicago, Mr. Burnham resigned from the Lick Observatory, and on his

return to Chicago accepted the position of Professor of Practical Astronomy in the University. Seven years later he became astronomer in the Yerkes Observatory, which began activity in 1898. Meanwhile, he had, in February 1894, received the Gold Medal of the Royal Astronomical Society. On that occasion the President remarked: "The line of work that he laid out for himself to accomplish he has successfully carried through. It is as arduous as it is unpretending; and when more than twenty years have been devoted to it, and the success which has attended it has been so remarkable, it does honour to the Society to recognise the high estimation in which it holds this work by awarding to its author the greatest distinction it can confer." In 1898 Professor Burnham was elected an Associate of the Society, Professor Barnard and the late Professor Keeler being elected at the same time. Recently he resigned his legal position in Chicago, and intends to devote himself solely to astronomy in the future.

With the great 40-inch Yerkes refractor at his disposal, Professor Burnham resumed his work on double stars. The first volume of "Yerkes Observatory Publications" bears the title: "A General Catalogue of 1290 Double Stars discovered from 1871 to 1899 by S. W. Burnham." This monumental work appeared in 1900. Micrometrical measures of each pair were given, and, in the case of computed binaries, the elements of the orbits. In preparing the catalogue he had the assistance of numerous observers of distinction. In the catalogue he investigates the distribution of the double stars in magnitude. The maximum number is reached at the eighth magnitude. It may be here remarked that the majority of Professor Burnham's pairs are very close. He divides his double stars into two classes, one of which comprises pairs in which the components are separated by less than one second of arc, while the second class contains stars whose distance is between one and two seconds.

After the publication of the catalogue, Professor Burnham devoted his work, with the 40-inch Yerkes telescope, to the

remeasurement of known, and in some cases neglected, pairs. These measurements were made in 1900 and 1901, and the results were published in "The Decennial Publications of the University of Chicago" in 1902. In the course of these measurements eighteen new pairs were discovered, which are numbered 1291 to 1308. "The reason why this number of new pairs is not larger will be readily understood," he remarks, "when it is explained that, in the first place, the finding of new pairs was no part of the work planned." Professor Burnham has done much for double-star astronomy in studying neglected pairs. He has not worked for the mere sake of discovery, for it is much better to know the particulars of a few systems thoroughly than to catalogue thousands of double stars of which nothing is known. Professor Burnham has carefully examined and measured every double star discovered by him, so that discovery of new pairs has not been his sole object. Possessed of exceptionally keen eyesight, he is scrupulously accurate and careful. Of some of the double stars discovered by the distinguished American astronomer it has been well said: "Such close doubles as some of these not one person in a thousand would be likely to see, even if he looked through the best and largest telescope." It is also said of Mr. Burnham that he knows all his double stars individually, and can speak of the peculiarities of each without reference to the catalogue.

The name of S. W. Burnham now stands beside those of William and John Herschel, Wilhelm and Otto Struve, as one of the five greatest discoverers of double stars who have ever lived. His work in that branch of astronomy has not only resulted in many extraordinary discoveries, but he has set a brilliant example of what perseverance, energy, and care will do in the discovery of stellar systems. Consequently, double-star observers, inspired by his example, have multiplied, and the study of double stars is now widely pursued. It may be confidently asserted that in the history of nineteenth-century astronomy the name of S. W. Burnham will deservedly occupy an honoured place.

Nils Christopher Dunér.

AMONG the illustrious astronomers who have increased our knowledge of the Universe by means of observation, a high place is occupied by the great Swedish astronomer who forms the subject of the present chapter. Professor Dunér has done much for purely telescopic observation, but he has done still more for spectroscopic astronomy. His discoveries undoubtedly gain for him a position second to none among living spectroscopists.

Nils Christopher Dunér was born on May 21, 1839, at Billeberga, a village in the province of Scania, South Sweden. He received his education at the University of Lund, where he passed his examination in 1855, and graduated Doctor of Philosophy in 1862. In 1861 and 1864 he took part under his friend the famous explorer, the late Professor Nordenskiöld, in the Swedish expeditions to Spitzbergen; and in 1865 he published, in conjunction with Nordenskiöld, a chart of that group of islands. Meanwhile he turned his attention to astronomy, and was in 1864 appointed observer in the Observatory of Lund, which was for many years directed by the late distinguished astronomer and mathematician, Axel Möller, famed for his researches on the motions of comets.

On the completion of the Lund Observatory in 1867, Dr. Dunér commenced a series of measurements on double stars. The results were published in his "Measures micrométriques d' étoiles doubles," which appeared in 1876. He also devoted much attention to computing the orbits of binary

Nils Christopher Dunér.

(Photo. by Alfred Dahlgren, Upsala.)

stars. For instance, he found a period of 45½ years for the star known as Struve 2173. For ξ Ursæ Majoris, the well-known double, discovered in 1780 by Herschel, he found 60¾ years; and this period, Mr. Gore says, "is perhaps the best." For η Cassiopeiæ, Dr. Dunér computed an orbit of 176 years. To star-colours much attention was given, the colours of the various doubles being carefully noted. These researches gained for him a great reputation as a practical astronomer, and placed him in the front rank of observers of double stars.

Early in 1878 Dr. Dunér commenced his important researches in spectroscopic astronomy. His attention was devoted to red stars of Secchi's third and fourth types (Professor Vogel's type IIIa and IIIb), and the results were embodied in a descriptive catalogue published at Stockholm in 1884, with the title; "Sur les étoiles à spectre de la troisième classe." The catalogue contained particulars of the spectra of 352 stars with banded spectra, 297 of Secchi's third type, and 55 of his fourth. In 1884 Dr. Dunér was opposed to Secchi's conclusion that bright lines could be observed in the spectra of red stars. At Upsala, however, where a much larger instrument became available, he was, in his own words, "able to detect without difficulty bright lines in various spectra, which at Lund were either invisible or at least could not be discovered." At Upsala he revised his previous spectroscopic work at Lund. His identification of bright lines in these spectra is confirmed by photographs obtained by American astronomers.

Dr. Dunér, at Lund, carefully determined the wave-lengths of the lines and bands in the spectra of Dr. Vogel's Class IIIa (Secchi's third type). He is perhaps the greatest authority on stars with banded spectra, and has devoted considerable attention to their evolutionary position. He is favourable to the opinion of Dr. Vogel, that stars of the Classes IIIa and IIIb, the third and fourth types of Secchi, represented by *Betelgeux* and 152 Schjellerup, represent alternative roads for stars in the solar type in their decline into dark stars. Dr. Dunér was unable to discover a star with a spectrum

intermediate between the second and fourth types according to Secchi, while there are many examples of the transition from the second to the third. To use his own words; "There must be a phase of development, especially for the fainter stars, in which it is impossible to distinguish which of the two types the spectrum should be assigned to. . . . The chief characteristic of the type (IIIb.) is the presence of the three broad, nebulous bands, which owe their origin to a hydro-carbon compound. Accordingly the observer will note either the presence or absence of the bands, and will conclude that the spectrum is respectively of Type IIIb or Type IIa."

Dr. Dunér was enabled to discover a spectrum which, he considers, throws some light on the question of how a spectrum of Dr. Vogel's Class IIa can develop into one of IIIb. This star is known as Birmingham 541, and in its spectrum the Swedish astronomer was enabled to perceive very faint bands, the development of which has progressed very slightly. "No intermediate condition between the spectra of Types IIa and IIIb properly exists; the transition from the one to the other has already occurred before the first traces of it are noticed." Stars of Secchi's fourth type are noticed to condense strongly towards the Milky Way, and Dr. Dunér remarks that these orbs conform to the law governing the structure of the Universe, a condensation towards the galactic plane.

As a discoverer of variable stars, Dr. Dunér's reputation is an enduring one. At Lund, he detected in 1878 the variable V Coronæ, in 1880 W Herculis, in 1881 S Aurigæ and V Ophiuchi. In 1884 he discovered V Boötis, a long-period variable with a mean period of 256 days. At maximum, the star is from the sixth to the seventh magnitude, and at minimum, from the ninth to the tenth. To variable-star astronomy Dr. Dunér has given much attention, and he is one of the directors of the Astronomische Gesellschaft Committee on variable stars.

In 1888 Dr. Dunér was appointed Professor of Astronomy in the University of Upsala, and director of the Observatory there. His first great work at Upsala was on the rotation of

the Sun, and his investigations resulted in one of the most remarkable spectroscopic discoveries which has ever been made. As is well known, the telescopic researches of Carrington and Spörer on sun-spots, showed that while the rotation of the Sun occupied less than twenty-five days at the equator, it was increased to over twenty-seven days at the fifteenth degree of Solar latitude. Dr. Dunér's conclusions regarding the Sun's rotation were published in his great memoir, entitled "Recherches sur la Rotation du Soleil," which was presented to the Royal Society of Sciences in Upsala, 14th February 1891. Dr. Dunér measured the Sun's rotation by means of Doppler's principle.* He selected two lines of iron in the red portion of the Solar spectrum and compared their positions with a pair of oxygen lines, which, being caused by absorption in the Earth's atmosphere, were unaffected by the Sun's rotation. The work, which extended over three years, showed that the displacements between the solar and telluric lines indicated rotation, on either side of the equator, in 25½ days. Professor Dunér measured the displacements up to within fifteen degrees of the poles, and brought out the surprising fact that the rotation period is there protracted to thirty-eight and a half days. These results were confirmed by Dr. Bélopolsky's and M. Stratonoff's researches on the movements of faculæ. With reference to the equatorial acceleration of the Sun, Professor Dunér remarks—"I must confess that this difference between the rotation periods in the different latitudes appears to me incomprehensible, and constitutes one of the most difficult problems in astrophysics." No really satisfactory theory of the remarkable fact which the great Swedish astronomer demonstrated has yet been propounded, although there have been many speculations on the subject.

In the same memoir, Professor Dunér made public his researches on the spectra of sun-spots. His observations showed the fundamental sun-spot spectrum to be indistinguishable from that of the general solar spectrum, proving

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* The first spectroscopic measures of the solar rotation were made by Zöllner, Vogel and Young.

the darkness of the spots to be due to increased absorption and not to diminished radiation. He also confirmed Professor Young's discovery of numerous lines in the spot-spectrum. Perhaps, however, Dr. Dunér's most remarkable researches have been on variable stars. In two cases he has been able to tell us of the exact constitution of stellar systems which no human eye has seen or ever will see. In regard to his work on Y Cygni, it is said that, "His theory is one of the most ingenious and brilliant results which the history of these objects has developed."

Y Cygni, the variability of which was detected by Dr. Chandler in 1886, varies from the 7·1 to 7·9 magnitude in a period of nine hours. It was soon found, however, that these light-changes recurred with great irregularity. In less than two years the phases differed by no less than seven hours from the calculated times. There seemed to be no explanation of the subject until it was investigated by Dr. Dunér. A series of observations on the brilliance of the star, conducted with the 6½-inch refractor at Upsala—generally employed for comet-seeking—in 1891 and 1892 convinced him in the latter year that two eclipses take place in the course of one revolution: one star occults the other.

Professor Dunér showed that the intervals between minima were thus, one day, nine hours; one day, fifteen hours; one day, nine hours, and so on. Thus, the first, third, fifth, seventh sets of minima obeyed a different law from the second, fourth, sixth, and eighth. He explained this by showing that two stars revolve round their centre of gravity in less than three days, alternately occulting each other, while the ellipticity of the orbit explains the irregularity of the light changes. In April 1900 Dr. Dunér gave his final conclusions as follows:—"The variable star Y Cygni consists of two stars of equal size and equal brightness, which move about their common centre of gravity in an elliptical orbit whose major axis is eight times the radius of the stars." He also stated the exact period of revolution and the eccentricity of the orbit.

In Professor Dunér's opinion, his researches on the variable

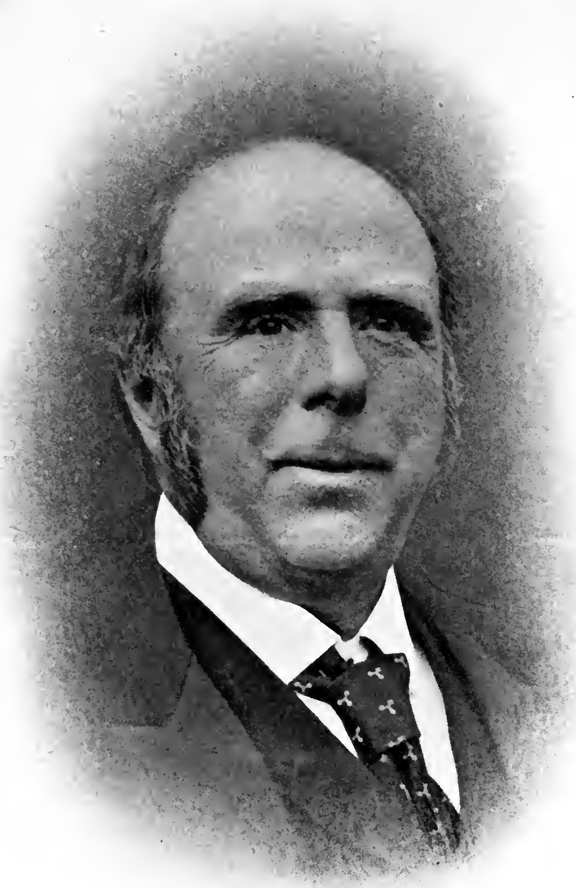
Z Herculis, discovered at Potsdam in 1894, are the fruit and application of his theory of Y Cygni. In the year of its discovery, he found that Z Herculis had two minima of unequal period, forty-seven and forty-nine hours respectively. Accordingly, he concluded that the variation was caused by the revolution of two stars of unequal brilliance in a period of four days. In his words: "Z Herculis consists of two stars of equal size, one of which is twice as bright as the other. These stars revolve round their common centre of gravity in an elliptical orbit, the semi-axis major of which is six times the diameter of the stars." It was also inferred that the plane of the orbit lies in our line of sight, while Dr. Dunér stated the eccentricity and the inclination almost with certainty. The stars were stated by him to revolve in 3 days, 23 hours, 48 minutes, 30 seconds.

In two cases Dr. Dunér has been able to tell us of the movements of stars in systems which are for ever invisible. He has solved the great mystery of one of the most irregular variables and has brought order out of apparent confusion. It is very wonderful that an astronomer, by a discussion of the irregularities of the light changes of a star, is enabled to tell us the exact elements of a stellar system plunged billions of miles in the depths of space.

Professor Dunér's discoveries and investigations have been so numerous that we cannot mention them all here. He has received numerous honours, both Swedish and foreign. He is member of Swedish and foreign academies and scientific societies and an Associate of the Royal Astronomical Society. He has received three times the Swedish Wallmark Gold Medal, and also the Rumford Medal of the Royal Society of London and the Lalande Prize of the French Academy of Sciences. In 1901 he was appointed Perpetual Secretary of the Royal Society of Sciences in Upsala.

Astronomical science owes much to the untiring and laborious researches of Professor Dunér. His studies of double stars, of the stellar types, and his conclusions as to stellar evolution, his researches on the rotation of the Sun, and

his investigations on variable stars, have been fruitful of new discoveries and ideas. He has combined the qualities of the practical observer and the astro-physicist, and in both of these branches has made marvellous discoveries. His wonderful studies and investigations testify to the undaunted perseverance and conscientious earnestness of Sweden's greatest astronomer.



Sir Robert Stawell Ball.

(Photo. by J. C. Dinham & Son, Torquay.)

Sir Robert Stawell Ball.

Probably no British astronomer has gained such a great public reputation as Sir Robert Ball, the distinguished Irishman who occupies the Lowndean Professorship of Astronomy at Cambridge. Sir Robert Ball has the rare gift of bringing his extensive scientific knowledge down to the level of the average man; but he is also one of our greatest investigators in astronomy. He has proved himself the worthy successor of Bessel, Struve and Henderson in that most difficult branch of astronomy—the measurement of stellar parallax; while other branches of the science have been enriched by his investigations.

Robert Stawell Ball was born in Dublin on July 1, 1840. His father was Dr. Robert Ball, a well-known Irish naturalist. The future astronomer received his education under Dr. Brindley at Chester, and at Trinity College, Dublin. In 1865, having become devoted to astronomy, he was appointed assistant astronomer to the Earl of Rosse, at Birr Castle, Parsonstown, where the great six-foot reflector had been erected in 1845. He retained this position for two seasons. "During that time," he writes, "I passed many a fine night in the observer's gallery, examining different objects in the heavens with the aid of this remarkable instrument. At the time I was there the objects principally studied were the nebulæ, those faint stains of light which lie on the background of the sky." While employed at Parsonstown, he had the good fortune to witness the great shower of meteors which took

place on the night of November 13, and the morning of November 14, 1866. He records in his work, "In Starry Realms," that he was engaged studying the nebulæ, when an exclamation from an attendant at his side caused him to look up just in time to see a great meteor flash across the sky. Lord Oxmantown (afterwards Earl of Rosse) joined him at the telescope, and, in the astronomer's own words, "To count the number of the meteors baffled all our arithmetic."

In 1867, when twenty-seven years of age, Mr. Ball was appointed Professor of Applied Mathematics and Mechanism in the Royal College of Science for Ireland. In 1873 he was elected a Fellow of the Royal Society, and, in 1874, became Andrews Professor of Astronomy in the University of Dublin and fourth Astronomer-Royal for Ireland in succession to Dr. Brünnow, being appointed at the same time Director of the Dunsink Observatory. While employed at the Dunsink Observatory, Professor Ball made many valuable observations on the new star in Cygnus, which was discovered by Dr. Schmidt, at Athens, on November 24, 1876. His observations were conducted with the view of determining its distance from the Solar System. The sudden outbreak of the star, and its rapid decline seemed to suggest that *Nova* Cygni was perhaps not an extensive outbreak; in fact, that the star was comparatively near to our system. Professor Ball, in order to test this idea, made a series of micrometrical measurements, to find whether it was possessed of a measurable parallax. He found, however, by measuring the star in the two positions where the parallactic displacement was greatest that no certain parallax could be detected. The conclusion was then reached that *Nova* Cygni was not within measurable distance, and Professor Ball, in "The Story of the Heavens," showed that the new star was at least 20,000,000,000,000 miles from the Solar System.

In 1881 Professor Ball undertook at Dunsink Observatory a sweeping search for stars with large parallaxes. He examined 450 stars, and of these only one, numbered 1618 Groombridge, of the sixth magnitude, gave signs of measurable distance. Professor Ball also remeasured the parallax of 61 Cyngi, both

in 1878 and 1884. Dr. Brünnow, the German astronomer, when Astronomer-Royal of Ireland, had commenced a series of measurements on 61 Cygni, which were continued by Professor Ball, who reached the conclusion that the parallax of 61 Cygni was 0·468″, confirming the result reached by Otto Struve, and indicating a distance of forty billions of miles.

A number of other investigations were carried out at the Dunsink Observatory about the same time. Professor Ball observed the transit of Venus on December 6, 1882. He records that the morning was as unfavourable as could be imagined. But the clouds broke, and the Professor and his assistant, Mr. Rambaut, obtained altogether eighteen measures. Professor Ball received as a reward for his services to science the Cunningham Gold Medal of the Royal Irish Academy; in 1884 he became Scientific Adviser to the Commissioners of Irish Lights; and he received the honour of knighthood on January 25, 1886.

Professor Ball's first astronomical work was his "Elements of Astronomy," published in 1880. This was followed by the well-known "Story of the Heavens," which appeared in 1886. This is perhaps one of the most comprehensive, and at the same time popular, treatises on astronomy which has been written. A second edition was published in 1900. In 1881 and 1887 Sir Robert Ball delivered the course of lectures at the Royal Institution, and, on his recollections of both, was founded his popular work, "Star-Land," which appeared in 1889, a second edition being issued ten years later. In 1889 he published "Time and Tide; a Romance of the Moon," a popular exposition of Professor G. H. Darwin's theory of tidal friction. Sir Robert Ball is one of the warmest supporters of this theory, and this fact should tell greatly in its favour. He is one of the most careful of astronomical investigators; he never supports a theory unless it appears to him to be practically proved. Any theory, therefore, which is supported by Sir Robert Ball is deserving of serious consideration.

Professor Ball's career as a public lecturer began in 1874, the year of his appointment as Astronomer-Royal for Ireland,

his first lecture being on the transit of Venus, an astronomical phenomenon which was then attracting much attention. From this time his popularity greatly increased. In 1881 he delivered the Inaugural lecture at the opening of the new hall of the Midland Institute in Birmingham, the subject being "A Glimpse Through the Corridors of Time." In 1881, also, he was chosen to lecture before the Royal Institution. The course of lectures was repeated in 1887, and on Sir Robert Ball's recollections of both, was founded his volume "Star Land." When the British Association met in Montreal in 1884, Dr. Ball delivered the public evening lecture. In the same year he visited the United States, lecturing at Philadelphia before the American Association, and at Boston before the Lowell Institute. For the past twenty years his reputation as a public lecturer has steadily increased, and it has been said of him—"There is no important town in England, Scotland, Ireland or Wales, and no important scientific institution in the country, where Sir Robert Ball has not lectured, and in most cases lectured often. . . At a very moderate estimate over one million people have heard him lecture."

Towards the end of 1892, Sir Robert Ball was appointed Lowndean Professor of Astronomy and Geometry at Cambridge, and Director of the Cambridge Observatory in succession to Professor Adams. Sir Robert Ball's successor at Dunsink was Dr. A. A. Rambaut, his assistant, who held that position until 1897. Since his appointment, Sir Robert Ball has published a considerable number of works. "In Starry Realms," a popular description of recent scientific investigations, was published in 1892, at the same time as Sir Robert's admirable "Atlas of Astronomy." This was followed by "The Story of the Sun," perhaps his most elaborate and technical work, which appeared in 1893. In this volume he discusses the various phenomena connected with the great luminary, ending with a chapter on the movements of the Solar System. Sir Robert Ball expresses his views on the construction of the heavens in the following words:—

"If we could look on the Sidereal System from some external

point which would enable us to view sidereal pnenomena in their proper perspective, we should find that the group to which our Sun belonged, in so far as it consisted in stars visible to us, was a limited one. This musi be so, even though the group included all the stars visible through our telescopes; even though it included all the stars in the Milky Way; even though it included the faintest point of light that ever succeeded in imprinting its image on the most sensitive photographic plate after hours of exposure. This unnumbered host is still only a cluster, occupying, comparatively speaking, an inexpressibly small extent in the ocean of infinite space."

Sir Robert Ball has done much for speculative astronomy. In his work on "The Cause of an Ice Age" (1890), he theorises on the connection between the precession of the equinoxes and the Ice Ages, concluding the latter to be the product of the former. In "The Story of the Heavens" he discusses the probable origin of meteorites. He rejects the idea, suggested by Laplace and Olbers, that they were ejected by lunar volcanoes, while he docs not associate them with meteoric swarms. After careful discussion, he finds that the meteorites which fall to the Earth cannot have come from any other planet, and, accordingly he concludes that they were originally ejected by the volcanoes of the Earth many ages ago, when in an active state, showing that a body leaving the Earth would, at each revolution, intersect the terrestrial orbit. There is much to be said in favour of this theory, which gained the support of Mr. Proctor and M. Flammarion; but it is not accepted by Sir Norman Lockyer and Professor Schiaparelli, who regard meteorites as merely larger members of meteoric swarms. The question, however, requires further investigation.

"The Story of the Sun" was followed in 1894 by "In the High Heavens," and in 1895 by "Great Astronomers," in which Sir Robert Ball sketched the lives of the famous students of the heavens from the days of Hipparchus to the present time. In 1900 he published his admirable little work, "A Primer of Astronomy." In his numerous books Sir Robert Ball, like M. Flammarion, impresses on his readers the vastness

of the Universe and the marvels of nature. As a sample of his noble writings take the following passage on light ("The Story of the Sun") "It sometimes seems that in the contemplation of the Sun's radiation, our eyes, even with all their perfections, are just as imperfect in interpreting fully what the Sun dispenses, as would be the ears of a man who could only hear the beating of a drum when attempting to listen to an orchestral performance of a beautiful symphony. The solemn tones of the organ, the exquisite delicacy of the stringed instruments, would be alike inaudible; all that he could hear would be the tones of a solitary instrument. Almost equally imperfect are our eyes for the interpretation of those marvellous radiations which the Sun sheds abroad with such prodigality. His beams really contain a vast keyboard of vibrations, of which our eyes can only disclose to us a couple of octaves. Here and there within the mighty compass of the instrument, we are able to devise a photographic plate, or a Hertzian resonator, to astonish us with a few additional octaves, but of the full volume of the harmony we are almost entirely ignorant. When we think that the Sun pours forth its radiations with such prodigality that our Earth is only able to intercept the two-thousand-millionth part of the whole; when we think that the other Suns in space, to the number of many millions, are each of them simultaneously filling the ether with their orchestra of vibrations; when we think of the marvellous delicacy with which that medium transmits all these vibrations —we begin to realise the majesty of the words, 'Let there be light!'"

In the winter of 1900 Sir Robert Ball delivered at the Royal Institution a course of lectures, which in December 1901 were published in book form with the title of "The Earth's Beginning." Unlike Sir Norman Lockyer, Sir Robert Ball is a supporter of the Nebular Theory. But even among the supporters of the Nebular Theory there are differences as to the exact mode of the formation of our system. In several points Sir Robert Ball differs from other investigators. He considers that the materials which now form the Sun, the

planets and their satellites, were distributed through space in the form of a great nebula, which, if hotter than the surrounding space, began to radiate forth its heat. As a natural consequence it began to contract, the condensation being greatest at the centre. But, in addition to this central condensation, other and smaller regions in the nebula became also centres of concentration. Probably there were about six of these conspicuous centres, and numerous other smaller points were also distinguished from the surrounding fire-mist. The nebula, which, contracting, left the smaller centres of condensation behind, now forms the Sun, while these smaller portions condensed into the planets and their satellites. The nebula in the course of ages completely disappeared, being absorbed into the large and small centres of attraction. As a consequence, after the smaller bodies have cooled into more or less solid globes, the central body remains white-hot. Sir Robert Ball considers that the evolution of the systems of satellites surrounding Jupiter and Saturn to have been similar to the formation of the Solar System.

Regarding the relation between the present revolutions of the planets and the previous rotation of the Sun, Sir Robert Ball writes—"The materials now forming Jupiter were situated towards the exterior of the nebula, so that, as the nebula contracted, it tended to leave Jupiter behind. The period in which Jupiter now revolves round the Sun may give some notion of the rotation of the nebula at the time it extended so far as Jupiter. . . . Passing over the intermediate stages, we find the nebula contracting until it extended no further than the line now marked by the Earth's orbit; the speed with which the nebula was rotating must have been increasing all the time, so that though the nebula required several years to go round when it extended as far as Jupiter, only a fraction of that period was necessary when it had reached the position indicated by the Earth's track at the present time. . . . It drew in, until at last it reached a further stage by contraction into the Sun, which rotates in less than a month. Thus the period of Jupiter, namely, twelve years, the period of the Earth,

namely, one year, and the period of the Sun, namely, twenty-five days, illustrate the successive accelerations of the rotation of the nebula in the process of contraction."

Regarding the size of the nebula from which the Solar System was probably evolved, Sir Robert Ball remarks that in all probability it was not one of these gigantic objects similar to the Orion nebula or the great Spiral—which will probably develop, not into Solar Systems, but into clusters of stars—but comparable in size with the small planetary nebulæ which are recognised only by their spectra, and shine as stars of twelfth and fifteenth magnitude. The retrograde motions of the the satellites of Uranus and Neptune—long considered to be one of the stumbling-blocks to the acceptance of the Nebular Hypothesis—are explained in a satisfactory manner by Sir Robert Ball. He has shown that, probably the planes of the orbits of the satellites will undergo transformations which will eventually bring them to coincide with the ecliptic. "The movements of the satellites of Uranus and Neptune do not disprove the Nebular Hypothesis. They rather illustrate the fact that the great evolution which has wrought the Solar System into its present form has not finished its work; it is still in progress."

Sir Robert Ball is not only an observer and writer; he has acquired some fame as a mathematician. For a quarter of a century he grappled with a mathematical problem known as the "Theory of Screws," communicated to the Royal Irish Academy in eleven memoirs from 1872 to 1897. The solution of the problem was at last reached in 1896. Sir Robert Ball is a Fellow of the Royal Society, Honorary Member of the Royal Society of Edinburgh, and Member of the Royal Irish Academy. He is also a Fellow of the Royal Astronomical Society, and held the position of President for two years, from 1897 to 1899. He has served on the Council of the Society for many years.

The astronomical work of Sir Robert Ball is sufficient to gain for him an enduring place in the history of astronomy. In practical astronomy he is a master; he is one of our

highest authorities in speculative astronomy; while his reputation as a mathematician is almost as high as that as an astronomer. Ireland has produced few astronomers, but Sir Robert Ball's work should give an impulse to science in his native land.

Giovanni Celoria.

Among modern students of the heavens, a high place is occupied by the distinguished astronomer who holds the position of director of the Brera Observatory in Milan, that famous institution where so many remarkable discoveries have been made. Professor Celoria has devoted his attention to the older branches of astronomy, mathematical calculation and direct observing. He has made many remarkable and suggestive observations, which throw considerable light on the supreme question of the extent and structure of the Stellar Universe.

Giovanni Celoria was born on January 29, 1842, at Casale Monferrato, near Alessandria, in Piedmont. He received his early education at home, and later entered the University of Turin, where he took his degree as engineer in 1863. He then turned his attention to mathematics and astronomy, pursuing the latter science at the Observatories of Milan, Berlin, and Bonn. In 1866 he received the appointment of aide-astronomer at the Brera Observatory, where Professor Schiaparelli was director and Tempel—the famous German observer and discoverer of comets, who died in 1889—first assistant. In 1870 Signor Celoria commenced to contribute to the "Scientific and Industrial Annual," an annual review of astronomy. When in 1873, on the death of Donati, Tempel was called to Florence as director of the Arcetri Observatory, Signor Celoria was appointed second astronomer in the Brera Observatory. In 1875 he became, in addition, Professor of

Giovanni Celoria.

(Photo. by G. B. Ganzini, Milan.)

Theoretical Geodesy in the Technical Institute of Milan. To geodesy, an interesting branch of astronomy, he has given much attention.

Professor Celoria's remarkable paper on the distribution of the stars and the construction of the heavens appeared in 1878. He made a count of the stars visible in a refracting telescope of 4 inches in aperture, in the zone from the equator to the sixth parallel of north declination in a circle extending round the heavens, enumerating between eighteen and twenty-five times the number of stars contained in the *Durchmusterung* of Argelander and Schönfeld. Professor Celoria's research brought out the fact that, among even the fainter stars, the individual stars increase rapidly in density from the galactic pole to the plane of the Galaxy itself. This is confirmed in regard to the lucid stars by the independent and differently directed researches of Professor Schiaparelli, Mr. Gore, and the late Mr. Proctor. In the dark rift in the Galaxy in Cygnus, Signor Celoria's star-gaugings revealed a marked paucity of stars down to the eleventh magnitude, the lowest order of stars shown by his telescope—a comparatively small one. This observation was a remarkable one, showing as it did the close connection between the clouds of the Galaxy and the nearer stars.

Professor Celoria's gauges of the heavens led him to the conclusion that the phenomenon of the Galaxy results from the existence of two galactic rings * inclined to each other at an angle of about nineteen or twenty degrees. In his opinion, one of these rings consists of faint and distant stars, the ring of bright stars being supposed to lie nearer to our system. According to Professor Celoria's theory, the distant stars are included in a great circle which passes through the constellations Sagitta, Auriga, Monoceros, and Scutum. The nearer and brighter ring is supposed to include the branch of the Milky Way in Ophiuchus, and also the *Hyades* and *Pleiades*, and a belt of bright stars which traverses the constellations

* In this respect Professor Celoria's theory agrees with that advanced by the late Dr. Gould.

Orion, Canis Major, Argo, Centaurus, Lupus, and Scorpio, in the southern hemisphere, and Taurus, Perseus, Cassiopeia, Cepheus, Cygnus, and Lyra, in the northern. Professor Celoria also drew attention to the remarkable fact that stars down to about the eleventh magnitude are much more numerous in the region of the sky near Aquila than in the opposite region in Monoceros, a fact which suggests that his telescope penetrated farther into space among the stars of Aquila, and that our Solar System is situated nearer to Aquila than to Monoceros.

As is well known to students of astronomy, in some portions of the heavens the commencement of the Galaxy is so abrupt that, to quote Miss Clerke, "the line of demarcation is so sharp that a telescope may have one half of its field crowded with galactic stars, while the other half is well-nigh blank," while in other portions of the heavens, the stars slowly increase in density towards the galactic plane. It was pointed out by Signor Celoria that the fainter the stars observed, the more abruptly the Galaxy commences, while an increasingly gradual condensation accompanies the brighter stars. This is a remarkable fact, and has some bearing on the question of the structure of the heavens. From theoretical considerations, Professor Celoria concluded that the Milky Way is really a region of stellar condensation, and thus showed the old "disc theory" to be quite untenable.

Still another remarkable observation was made by Professor Celoria, which throws much light on the much-disputed question of the infinity or non-infinity of our Universe. The observation in question was made in the course of his star soundings at the north galactic pole where his small refractor, showing stars barely to the eleventh magnitude, there revealed exactly the same number of stars as Herschel's large reflector, indicating that further increase of optical power will not increase the number of stars visible in that direction. Here, at least, the Italian astronomer appears to have sounded the Stellar Universe, and there is no escape from the conclusion that our Universe is limited in extent; for, were the Universe

infinite, and indefinitely extended in all directions, Sir William Herschel's large telescope, which showed much fainter stars than the eleventh magnitude, would then show many times the number of stars seen with Signor Celoria's small one. Nor will the hypothesis of the extinction of light afford an adequate explanation. Even were there an extinction of light, the larger telescope would still show more stars; and the theory of light extinction—at least, as put forward by the elder Struve—is now practically abandoned. There is but one conclusion to be drawn from Professor Celoria's observations—that our Universe is finite in extent, whether or not there are other universes beyond; and this is the view accepted by the chief authorities on the subject. To the distinguished Italian astronomer belongs the credit of having pierced through the stratum of stars constituting the Visible Universe.

About the year 1879 Professor Celoria turned his attention to the investigation of the ancient solar eclipse known as that of Agathocles, and of other eclipses of the Middle Ages, principally those of 1238, 1239 and 1241. The object of Professor Celoria, in these calculations, was to verify for those remote epochs the accuracy of the numerous lunar tables, and to investigate the rate of the acceleration of the Moon's mean motion. His investigations of the eclipses of the Middle Ages appeared in the publications of the Brera Observatory. His masterly work in this line, however, was the exhaustive paper, "On Some Ancient Solar Eclipses, and on that of Agathocles in Particular," which was in 1880 published in the proceedings of the Academia dei Lincei at Rome. An idea of the mathematical work accomplished by Signor Celoria will be gained from the fact that he investigated the circumstances of no fewer than 135 of these eclipses—covering the period from B.C. 322 to 99—devoting special attention to the eclipse named after Agathocles, tyrant of Syracuse, in whose lifetime it look place, and which was mentioned by two Roman historians. The date of this eclipse having been fixed at 309 years before the Christian Era, it was at once obvious that it would be useful for investigation of the Moon's

motion. The conclusion of Professor Celoria was that the theoretical values of the acceleration of the lunar motion were reconcilable with the eclipse of Agathocles, a few minor corrections being made. In this work, Professor Celoria not only gained for himself a high position as a mathematician, but rendered an inestimable service to mathematical astronomy.

In 1888 Professor Celoria commenced to compute the orbits of double stars, in which branch of research he has gained a considerable reputation. The paper of 1888 was followed by others in 1889 and 1890, in which he computed the orbits of the binary stars Struve 3121, μ Herculis, γ Coronæ Borealis, β Delphini, and Otto Struve 298. For β Delphini, a binary discovered in 1873 by Mr. Burnham, he found a period of only seventeen years. Professor Celoria has gained a considerable reputation as an author on astronomical subjects. He has written popular monographs, entitled "The Moon" and "The Comets." Among his other works are: "Manual of Popular Astronomy," "Atlas of Astronomy," "Cosmography," "The Earth and the Universe." He has published many important scientific papers, which cannot all be enumerated here. Among these is a paper on the periodical and non-periodical variations of the temperature and climate of Milan. He also determined the difference of longitude between Milan and the cities of Padua, Modena, Venice, Genoa, Parma, Naples, Paris, and Nice.

In November 1900, on the resignation of Professor Schiaparelli, Signor Celoria was appointed to succeed him as first astronomer and director of the Milan Observatory. In 1902 he was appointed President of the Royal Italian Commission on Geodesy, a branch of research on which Professor Celoria is in Italy a recognised authority. His most recent paper, which appeared in 1901, after his appointment as director of the Milan Observatory, is a stellar catalogue bearing the title "Mean Positions for 1870 of 1118 Stars." The catalogue is of great value in showing the positions of the stars at that epoch.

Professor Celoria has gained for himself a very high position

among modern astronomers. He is one of the few astronomers who have devoted themselves to star-gauging with the object of throwing light on the problem of the construction of the Stellar Universe. His researches have brought out several remarkable facts—namely, that our Universe is not infinite in extent, that the stars down to the eleventh magnitude aggregate on the Milky Way, and that more stars are visible down to the eleventh magnitude in Aquila than in the opposite region of the heavens. It is by these and similar investigations that we may hope to solve the supreme question of the form and extent of our Universe. Astronomy owes many remarkable investigations to the able and enthusiastic researches of this illustrious Italian astronomer.

Agnes Mary Clerke.

A SOMEWHAT unique position in modern astronomy is occupied by the distinguished astronomer who forms the subject of this article. Miss Clerke's observations both on the heavenly bodies themselves and on celestial photographs have done much for the progress of astronomical science; but perhaps her greatest work has been that of the historian and careful thinker, and in this branch of astronomy Miss Clerke has deservedly earned a great reputation.

Agnes Mary Clerke is a native of County Cork, Ireland, where she was born on February 10, 1842. She is the daughter of the late John William Clerke. At the age of eleven or twelve she read Sir John Herschel's "Outlines of Astronomy," and from that date she was passionately devoted to the science. From 1870 until 1877—when she settled in London—Miss Clerke resided in Italy, where she continued her astronomical investigations. Her first contribution to astronomical literature consisted in an article on "The Chemistry of the Stars," which was published in 1879 in *The Edinburgh Review.*

In 1881 Miss Clerke commenced writing her great book, "A Popular History of Astronomy during the Nineteenth Century." This work occupied her four years, and the volume appeared in the end of 1885. In her preface Miss Clerke points out that there are many reasons for preferring a history to a treatise on astronomy. In a treatise *what* we know is set forth, while a history tells us also *how* we came to know it.

Miss Agnes Mary Clerke.

(Photo. by Barraud, London.)

The book is divided into two parts: "Progress of Astronomy during the First Half of the Nineteenth Century," and "Recent Progress of Astronomy." The advantage conferred on astronomy by this great work can scarcely be overestimated. Written in a clear and lucid style, Miss Clerke's book should long hold its place as one of the standard works on the subject. The volume is scrupulously accurate, and is kept up to date by new editions, which have been published respectively in 1887, 1893, and 1902. The new matter is so interwoven with the old that the book resembles in that respect a new publication.

After the publication of her "History of Astronomy" Miss Clerke commenced to devote herself to the examination of celestial photographs. She made an attentive examination of one of Professor Pickering's photographic catalogues of 947 stars within one degree of the north celestial pole. As is well known, the stars of each fainter magnitude are about three times as numerous as the magnitude immediately brighter. Miss Clerke, however, after an examination, drew a diagram representing the distribution of these stars from the ninth to the fifteenth magnitude. "The small stars," she says, "are overwhelmingly too few for the space they must occupy if of average brightness; and they are far too few in a constantly increasing ratio." This is an indication that our Universe has definite bounds and that it is not infinitely extended. Indeed, Mr. Gore, arguing from these investigations of Miss Clerke—as well as from his own researches, to which we refer in another chapter—suggests that "a limit will soon be reached beyond which our most powerful telescopes and photographic plates will fail to reveal any further stars."

While Miss Clerke was engaged writing her work, "The System of the Stars," she was invited, in August 1888, to the Cape Observatory by Sir David Gill, who placed a telescope and spectroscope at her disposal. At the Cape, Miss Clerke surveyed the spectra of numerous southern stars. Among the stars specially studied was the famous gaseous star, γ Argus, the peculiarities of which were first pointed out in 1871 by the Italian astronomer Respighi. Her observations of γ Argus

were precisely in agreement with those previously made by Professor Copeland, but she also observed a deep absorption band below the cobalt line. "A vivid continuous spectrum," Miss Clerke remarks, "extends into the violet as far as the eye has power to follow it, and accounts for the brilliant whiteness of the star." At the Cape Observatory, she also made many valuable observations of star-colours. On her return to London, Miss Clerke was occupied with her important work, "The System of the Stars," which was published in the end of 1890. This valuable work, of which Miss Clerke intends to publish a second edition, is in every respect a masterpiece, and an important contribution to astronomical literature. By it Miss Clerke's reputation as an author was further increased. Her minute and detailed handling, and her clear and lucid exposition of abstruse astronomical theories make the work indespensable not only to the professional astronomer, but also to the general reader.

In 1893 Miss Clerke, for her astronomical writings, was awarded the Actonian Prize of one hundred guineas. She now commenced her work on "The Herschels and Modern Astronomy"—biographies of William, Caroline, and John Herschel—which was published in 1895 as one of the volumes in the Century Science Series. Miss Clerke also wrote the articles on astronomers—such as Halley, Bradley, Henderson, Goodricke, Airy, Adams—for the "Dictionary of National Biography." She has written numerous articles on her favourite science for the *Edinburgh Review* and the "Encyclopædia Britannica." Miss Clerke contributed the sections on "Astronomical History" and "The Solar System" to the "Concise Knowledge Astronomy," of which she was joint author, along with Mr. J. E. Gore and Mr. Alfred Fowler—assistant to Sir Norman Lockyer in the Solar Physics Observatory.

Perhaps Miss Clerke's most important work is her "Problems in Astrophysics," which appeared early in 1903. In her preface she remarked: "The object of the present work is not so much to instruct as to suggest. . . . Innumerable objects in the sidereal heavens remain neglected

mainly through inadvertence to the extraordinary interest of the questions pending with respect to them. In the following pages it has been sought to indicate some of these individually and in their relations to the larger meanings of cosmical research." The volume is divided into two parts, bearing the respective titles, "Problems in Solar Physics," and "Problems in Sidereal Physics." The volume is perhaps one of the most remarkable contributions yet made to spectroscopic astronomy. Besides being descriptive of astrophysical problems, the volume gives a very detailed insight into the history and present condition of astronomical spectroscopy. "We do not know of any other single source for so much of such information in the English language," writes Professor Payne of Minnesota, "as this remarkable book furnishes. It is written in popular language, and it presents preliminary results in astronomical work now in progress along the whole frontier line of solar science with such insight and fidelity, as to indicate rare practical judgment in weighing evidence for generalisation, and in drawing conclusions which have theoretical value." On the publication of "Problems in Astrophysics," Miss Clerke was, in February 1903, elected an Honorary Member of the Royal Astronomical Society, an honour conferred at the same time on Lady Huggins. This was the first occasion, for almost seventy years, on which ladies were elected to the Society, the only previous lady members being Caroline Herschel and Mary Somerville.

Miss Clerke's views on the construction of the heavens, on which subject she is a recognised authority, are similar to those expressed by Professor Newcomb, Mr. Gore, Professor Celoria, and other eminent astronomers. Our Universe, Miss Clerke points out, cannot be infinite. As there are three times as many stars of a given magnitude than of one immediately brighter, the decrease of brilliance is more than compensated for by the larger number of stars, so that, were the Universe infinite, there would be such a blaze of starlight as to banish night—granting, of course, as Miss Clerke remarks, that light suffers no extinction in space, an assumption in favour of which, she points out, there is not a particle of evidence.

"The sidereal system," she says in 'The System of the Stars,' "cannot be regarded as in any true sense infinite. The scale upon which it is constructed baffles, it is true, the utmost strain of the imagination to conceive; in the multitudinous splendour of its components, in the number and variety of the subordinate groups constituted by them, in the magnificient play of forces it unfolds, in the dim processes of development it suggests, it bears glorious witness to the power and wisdom of the Almighty Designer; yet it has limits." Miss Clerke does not attempt to assign these limits; she does not discuss the question of external galaxies, although she admits the possibility and probability of their existence.

Miss Clerke's style of writing is clear and concise, and she is specially successful in impressing the reader with the infinity of time and space and the scale on which the Visible Universe is constructed. The following passage from her "System of the Stars" not only gives her opinions on the important question of stellar evolution, but affords an example of her writings:—"The glory of the heavenly bodies, it is asserted, must come to an end. It results from a merely transitory state of things. The radiations, by virtue of which they shine, are the outcome of what may be figuratively termed the effort of nature to establish a universal thermal equilibrium. This condition will be attained when the frigid 'temperature of space' reigns in all the millions of bodies, which once were suns, and will thenceforth revolve amid 'darkness that may be felt'—the mechanism of their movements unimpaired, but inert, lifeless, and invisible. Is this, then, the predestined end? Science replies in the affirmative. That is to say, it knows no better. . . . That is all we know; at the brink of the ocean we pause, helpless to sound its depths, or number the modes of its manifestations, or predict the tasks of renovation or preservation committed to it. We can only recognise with supreme conviction that He who made the heavens can restore them."

Camille Flammarion.

(Photo. by Stebbing, Paris.)

Camille Flammarion.

Among the modern astronomers there is no greater name than that of the illustrious Frenchman, Camille Flammarion. This distinguished astronomer, who has the charm of describing the wonders of the heavens, and of impressing his readers with the marvels of the celestial bodies, possesses the capacity for original studies and investigations, which have been directed to the planets, to double stars, and especially to stellar motions. Indeed, there is scarcely a branch of astronomy which he has not enriched by his discoveries and investigations.

Born at Montigny-le-Roi, in the department of Haute Marne, on February 25, 1842, Camille Flammarion received his education in the Ecclesiastical Seminary of Langres. He was originally intended for the priesthood, but at an early age his attention was drawn to the science of astronomy. In his "Popular Astronomy" is reproduced a drawing by him of the comet which appeared in 1853, when he was eleven years of age. He writes: "A child thinks wonderful an ordinary comet, which, for the first time, gives him an idea of these celestial apparitions; this was how the comet of 1853 struck myself, if I may be permitted to recall a personal recollection, when, in the month of August of that year, I viewed it from the top of the ramparts of the ancient city of Lingons, shining with its calm light in the northern sky, still illuminated with the warm brightness of the summer twilight. I even made a drawing of its appearance, without suspecting that in the future this little drawing would have the honour of publicity."

Although educated in an ecclesiastical seminary, M. Flammarion did not take holy orders, choosing to pursue rather the study of astronomy. In 1858, at the age of sixteen, he became bachelor assistant to Le Verrier in the Paris Observatory, where he remained for only four years. In 1862 he studied at the Sorbonne under the great mathematician Delaunay, and during the next four years he held a post in the Bureau des Longitudes. In the same year he became editor of the *Cosmos*, and in 1865 he received the appointment of scientific editor of the *Siècle*. At an early age he began to publish books on astronomy. The first of these, "The Plurality of Inhabited Worlds," appeared in 1862, and has now reached its thirty-eighth edition. In 1865 M. Flammarion published his third work, "The Marvels of the Heavens," which was in 1872 translated into English by Mrs. Norman Lockyer; and about this time he commenced lecturing on astronomy, which further increased his reputation. In 1867 and 1868 he made several balloon ascents, with the object of studying the condition of the atmosphere at high altitudes. In the latter year was published his "Voyages Aériens," the result of his work in that direction. His work on "The Atmosphere," which was published in 1872, was translated into English by Mr. Pitman, and edited by the late Mr. Glaisher. In 1872 M. Flammarion visited Rome, where he was received at the Vatican by Pope Pius IX. In conjunction with his friend Father Secchi he observed the prominences of the Sun from the Observatory of the Collegio Romano. He was residing in Rome at the time of the great meteoric shower on November 27, 1872; but he did not observe it, as he had just recovered from a fever caught in the Pontine marshes.

In 1873 M. Flammarion made his first communication to the Paris Academy of Sciences on the subject of double stars. He soon distinguished himself as a binary star computer. For the famous binary ξ Ursæ Majoris he found a period of over sixty years, in agreement with the results of Dr. Dunér and other astronomers. For ζ Herculis he reached, after a careful discussion, a period of about thirty-four years; for

η Coronæ Borealis forty years; for γ Virginis he found one hundred and seventy-five years; and for 70 Ophiuchi ninety-two years. His reputation as a double-star computer was now established. He drew attention to the fact that a number of double stars investigated by him proved to be merely optical, that is, one of the stars had no connection with the other. In 1878 he communicated to the French Academy a long list of these optical doubles.

Perhaps M. Flammarion's most striking discoveries in stellar astronomy pertain to star-drift. As is known, the most prominent cases of star-drift, in Leo, Taurus, and Ursa Major, were pointed out by Proctor in 1870. The subject was soon taken up by M. Flammarion, who carefully drew charts of proper motion. His investigations demonstrated the existence of connected stellar systems formed by widely separated stars. One of the most interesting cases was the association of the bright star *Regulus* with an eighth-magnitude star known as Lalande 19,749. Measures by Christian Mayer in 1777 and by M. Flammarion in 1877 revealed the possession by both stars of a "common proper motion." In the same paper (November 1877) another case of star-drift in Triangulum was anuounced. Other interesting cases were those of the single star, ψ Aquarii, and the double, Struve 2993. The connection between θ Ursæ Majoris of the third magnitude, and 1618 Groombridge of the seventh, separated by a distance of 39 minutes of arc, was demonstrated by M. Flammarion. Two double stars in Cygnus, 17 Cygni and Struve 2576 also possess a common proper motion, thus proving their connection. In his unrivalled language he says of these stellar movements—"Such are the stupenduous motions which carry every sun, every system, every world, all life, and all destiny in all directions of the infinite immensity, through the boundless, bottomless abyss; in a void for ever open, ever yawning, ever black, and ever unfathomable; during an eternity, without days, without years, without centuries, or measures. Such is the aspect, grand, splendid, and sublime, of the universe which flies through space before the dazzled and stupefied gaze of the

terrestrial astronomer, born to-day to die to-morrow, on a globule lost in the infinite night."

In a paper communicated to the Academy at the same time, M. Flammarion remarked that there exists in the Southern Hemisphere "a veritable current of stars" moving from the point opposite to the direction of the solar motion; and a list of these stars were given. This brings us to the subject of star-streams so carefully studied by the late Mr. Proctor and by Mr. Gore. In 1878 M. Flammarion published his "Catalogue of Double and Multiple Stars in Certain Motion," the result of laborious observations made on 10,000 double stars in the four years from 1873 to 1877. He found that 819 groups were in certain motion, and of these he measured 133 with the micrometer. In his work "Les Etoiles" M. Flammarion published another important catalogue of changes in the heavens. He constructed a comparative catalogue of all the stars observed for two thousand years. This was done by combining the catalogues of Hipparchus, Al-Sufi, Ulugh Beigh, Tycho Brahe, Hevelius, Flamsteed, Piazzi, Lalande, Argelander, and Heis, and the result was a list of stars which changed in brightness during the two thousand years. In the same work there was given a list of all the known variable stars in the heavens. M. Flammarion detected the relative variability of the double star γ Arietis, and of other stars.

Although M. Flammarion had gained a reputation as an author by his various works, his most important volume was undoubtedly "L'Astronomie Populaire," which appeared in 1879. In June 1880 the distinguished author received the Montyon Prize of the Paris Academy, and the work was selected by the Minister of Education for use in the public libraries. In a few years no less than 100,000 copies had been sold. In 1894 this masterly volume was translated into English by Mr. J. E. Gore, the distinguished astronomer.

In this work M. Flammarion suggested the existence of a new planet. He noticed that all the periodical comets in the Solar System have their aphelia near the orbit of a planet.

Thus Jupiter owns about eighteen comets, including Encke's and others of very short period; Saturn owns one, and probably two, including Tuttle's; Uranus two or three, among them Tempel's comet of 1866; and Neptune six, including Halley's and Olbers'. Now, the third comet of 1862 and the August meteors go farther out than the orbit of Neptune, and M. Flammarion suggested the existence of a great planet revolving round the Sun in about 330 years, at a distance of 4,000 millions of miles. He even gave in "Popular Astronomy," a diagram of the hypothetical orbit of the trans-Neptunian planet. The existence of such a planet has also been suspected by other investigators, but although searched for, it has not been found. All the same, this is no proof that it does not exist. Should such a planet be discovered it would be a prominent addition to our astronomical knowledge.

M. Flammarion commenced in 1871 to attentively observe the planet Mars at each opposition. In June 1873 he noticed that the north polar cap was reduced to a mere point; while in 1875 he could scarcely distinguish the polar spot owing to its small size, while the snows surrounding the south pole were at their maximum extension. M. Flammarion's important work "La Planéte Mars," which deals with the various Martian problems, appeared in 1892. The author admits the existence of Professor Schiaparelli's canals, but is unable to explain their duplication, although he considers it possible that, under special circumstances, companion-canals might result from a kind of mirage. "It would be impossible," writes Mr. Arthur Mee, one of M. Flammarion's warmest admirers, "to speak too highly of the noble book that we owe to this gifted and eloquent Frenchman, who has laid the world under a weight of obligation, and whose masterly effort must be the standard work on Mars for many a year to come."

In 1883 M. Flammarion founded his private observatory at Juvisy-sur-Orge, in the department of Seine-et-Oise. Here he has made valuable observations, assisted by various young astronomers. In the years 1892-1894 M. Flammarion made a series of observations on Venus. These observations did not

confirm those of Professor Schiaparelli, which indicated a period of rotation equal to that of revolution; they rather supported the period of twenty-three hours, originally found by Schröter and Di Vico. M. Flammarion confirmed the idea that snow exists at the poles of Venus, similar to that of Mars. He remarked that, as both poles were visible at the same time, the axis of the planet cannot have a great inclination to the plane of its orbit. His observations on Jupiter, commenced in 1868, have been continued at Juvisy. From a spot near the twenty-fifth parallel of latitude he found a rotation period of 9 hours, 55 minutes, 45 seconds. To Saturn, also, the great astronomer has given much attention. In 1896 and 1897 he determined the rotaton period as 10 hours, 14 minutes, 14 seconds.

M. Flammarion is a skilful draughtsman, and his volumes are illustrated by his own drawings of the various planets, delineations of the utmost delicacy and value. He has made very careful drawings of Mars and Venus, Jupiter and Saturn, and of the surface of the Moon. Since 1858 he has observed all the lunar eclipses visible at Paris. During the eclipse of June 1, 1863, the Moon gave out as much light as *Altair*. On October 4, 1865, M. Flammarion noticed that the bright streaks radiating from the crater Tycho remained visible during the eclipse. In regard to the eclipse of October 25, 1874, M. Flammarion pointed out that neither the "Connaissance des Temps" nor the "Annuaire du Bureau des Longitudes," the French official publications, accuratety predicted the circumstances of the eclipse. During the eclipse of October 4, 1884, the Moon almost entirely disappeared.

M. Flammarion founded in 1882 the review *L' Astronomie*, and in 1887 the Société Astronomique de France — a prosperous and popular organisation—of which he was the first president, and is now secretary. Several societies have been named after the illustrious astronomer, who has done as much to popularise science as any other living scientist. He has published two astronomical romances entitled, respectively "Urania" and "Lumen"; and one of his most recent

works is "The Unknown," in which he discusses the problems of spiritualism. At the Juvisy Observatory he has made determinations by means of a photographic chart of 356 circumpolar stars, of the north celestial pole. He has also given attention recently to photography of the Sun, to the aurora and terrestrial magnetism, and to the revision of Messier's Catalogue of clusters and nebulæ.

We have described Camille Flammarion as an astronomer; we have reviewed his labours in the cause of science. It now remains to estimate him as a writer. M. Flammarion has gained a reputation as an author as well as an astronomer. His writings leave on the mind of the reader a grand impression of the vastness of the Universe. In his works science, poetry, and religion exist in harmonious combination Take the following example ("Popular Astronomy," page 628):—

"Beautiful summer evenings, which slowly descend from the heavens on the bright day, still come to bathe the Earth with your golden halo! Open still to the perfumed breeze the gates of the winding valleys; allow still to fall like dew of the air the mist of the twilights; let the harmonious tints which imperceptibly fade away from the rosy west to the azure zenith still adorn this superb vault, that our delighted gaze may always wander in this floating depth. Sweet hours of evening, do not flee away! We love this universal calm which surrounds nature before it sleeps; we love this unchangeable peace which descends from the rising stars! Be present still at this profound meditation in which all beings participate as if they had consciousness; listen still to the last rustling of the quivering foliage! The starry sky which lights up, the earth which falls asleep—these are spectacles which draw us away from a world of clamorous passions, pleasures of the soul which we enjoy in peace."

Again, in his chapter on binary stars, he writes; "The double stars are so many *stellar dials* suspended in the heavens, marking without stop, in their majestic silence, the inexorable march of time, which glides away on high as here, and showing to the Earth, from the depth of their unfathomable

distance, the years and centuries of other universes, the eternity of the veritable Empyrean! Eternal clocks of space! your motion does not stop; your finger, like that of Destiny, shows to beings and things the everlasting wheel which rises to the summits of life and plunges into the abysses of death! And from our lower abode we may read in your perpetual motion the decree of our terrestrial fate, which bears along our poor history and sweeps away our generation like a whirlwind of dust flying on the roads of the sky, while you continue to revolve in silence in the mysterious depths of Infinitude!"

The following fine passage is from M. Flammarion's "Plurality of Worlds." "If our sight was piercing enough to discover, where we only see brilliant points on the black background of the sky, resplendent suns which revolve in the expanse, and the inhabited worlds which follow them in their path, if it were given to us to embrace in a general *coup d'œil* these myriads of fire-based systems; and if, advancing with the velocity of light, we could traverse from century to century, this unlimited number of suns and spheres, without ever meeting any limit to this prodigious immensity where God brings forth worlds and beings; looking behind, but no longer knowing in what part of the infinite to find this grain of dust called the Earth, we should stop fascinated and confounded by such a spectacle, and uniting our voice to the concert of universal nature, we should say from the depths of our soul: Almighty God! how senseless we were to believe that there was nothing beyond the Earth, and that our abode alone possessed the privilege of reflecting Thy greatness and power."

M. Flammarion says in his work "The Marvels of the Heavens"—"O Night, how sublime is thy language to me! where are the souls to whom the spectacle of starry night is not an eloquent discourse? where are those who have not been sometimes arrested in the presence of the bright worlds which hover over our heads, and who have not sought for the key of the great enigma of creation? The solitary hours of night are in truth the most beautiful of all hours, those in which we have

the faculty of placing ourselves in intimate communication with great and holy nature."

M. Flammarion is one of the warmest supporters of the theory of the plurality of worlds. In his works he impresses on the mind the smallness and insignificance of everything earthly, and the infinitude of space. He despises the petty spites of the various nations; he very truly remarks that, while civilised nations spend very little for the advancement of science, they waste immense sums of money annually, in order to support armies, for no other purpose than the destruction of millions of the earth's inhabitants. "In the eternity of duration, the life of our proud humanity, with all its religious and political history, the whole life of our entire planet, is but the dream of a moment."

"The forces of nature," says M. Flammarion, "have life as their supreme end. Life is universal and eternal, for time is one of its factors. Yesterday the Moon, to-day the Earth, to-morrow Jupiter. In space there are both cradles and tombs." As M. Flammarion affirms, life may exist in many forms. To-day, he remarks, our scientists affirm that carbon is a necessity for the maintainance of life. Doubtless the inhabitants of planets revolving round Rigel and Deneb—stars chiefly characterised by silicon and titanium—know nothing of this supposed necessity of carbon. According to the French astronomer, space is infinite. Our Universe may contain one thousand million suns, a limited number. But it does not exist alone. Beyond, there are other universes. "Whatever be its extension, our Milky Way is but a point in the infinite."

In a recent article M. Flammarion thus expresses his views on the Universe: "Our science is but a shadow in the face of the reality. Infinity encompasses us on all sides, life asserts itself, universal and eternal, our existence is but a fleeting moment, the vibration of an atom in a ray of the Sun, and our planet is but an island floating in the celestial archipelago, to which no thought will ever place any bounds. Never lose sight of the fact that space is infinite, that there is in the void neither height, nor depth, nor right, nor left; and in time

neither beginning nor end. We must understand that our conceptions are relative to our imperfect and transitory impressions, and that the only reality is the Absolute."

Astronomers owe to Camille Flammarion a lasting debt of gratitude. His remarkable researches have enriched the science with new discoveries and investigations, while his profound reasoning, his sweeping conceptions of the Universe, show us our true position in the midst of the infinite space which surrounds us on all sides.

Hermann Carl Vogel.

(Photo. by Selle & Kuntze, Potsdam & Spandau.)

Hermann Carl Vogel.

To the leading astronomer of Germany we owe much of our knowledge of both planetary and stellar spectroscopy. We have already referred to the careful observations, ingenious methods, and wonderful discoveries of Sir William Huggins, the investigations and speculations of Sir Norman Lockyer, and the laborious researches of Dr. Dunér. But to the great astronomer who forms the subject of this article we owe the cultivation of a different branch in spectroscopy, the precise measurement of stellar motions. Spectroscopic astronomy has latterly become one of the most accurate branches of astronomical science as a result of the unwearied labours of Professor H. C. Vogel, the director of the Astrophysical Observatory at Potsdam.

Hermann Carl Vogel was born in Leipzig on April 3, 1842. He is the youngest son of Dr. Carl Vogel, a famous schoolmaster in Leipzig, and brother of Dr. Eduard Vogel, the astronomer and well-known African explorer, who met his death at Wadai in 1857. At the age of twenty-one the future astronomer entered the University of Leipzig, where he remained for four years. Meanwhile he had become devoted to astronomy, his interest in the science being due to his acquaintance with J. C. F. Zöllner, the well-known German astronomer whose death in 1882 at an early age was a distinct loss to science. In 1865 Herr Vogel was appointed assistant in the Leipzig Observatory, and made two important series of observations on star-clusters and nebulæ, fixing with unsurpassed

accuracy the positions of 240 of these objects, of especial value in regard to any discussion of nebular parallax. With the 8-inch refractor of the Leipzig Observatory he observed the double cluster in Perseus, determining the positions of 176 stars, ranging from the sixth to the thirteenth magnitude.

In 1869, Dr. Vogel assisted Zöllner in his spectroscopic observations of the solar prominences. The following year he was appointed director of Von Bülow's private observatory at Bothkamp, in Holstein. In this position he devoted his attention chiefly to planetary and stellar spectroscopy. In 1871 he commenced these observations on the spectra of the stars which have rendered his name famous. He made a series of measurements of the displacement of the hydrogen line marked F, in the spectra of *Sirius*, *Vega*, *Procyon*, *Capella*, and *Altair*, and he published in the *Astronomische Nachrichten* his results regarding their motion in the line of sight. He also executed a series of observations on the spectra of the planets. Although some investigations in this line of research had been previously made by Father Secchi and Sir William Huggins, the field of research was almost untrodden. While employed at Bothkamp, Dr. Vogel succeeded in measuring the absorption bands in the spectra of the planets; and the results of his work were made public in his "Spectra der Planeten," which appeared in 1874.

Mercury, which was examined spectroscopically by Dr. Vogel in 1871, was suspected by him to betray signs of some atmospheric lines, but it was not possible to get the observations free from the influence of the Earth's atmosphere. In the spectrum of Venus, however, the astronomer could detect only the slightest difference from that of the Sun. Dr. Vogel paid much attention to Venus, and his drawings of its surface did not agree with the theory that the planet rotated in a short period, and were partially confirmatory of the results afterwards reached by Professor Schiaparelli. In November 1871, Dr. Vogel and Dr. O. Lohse saw the dark hemisphere of the planet partially illuminated with secondary light, and suggested that the appearance might result from a very extensive twilight.

Dr. Vogel's examinations of the spectra of Jupiter, Saturn, and Uranus revealed the existence of absorption bands in their spectra. On the band in Jupiter's spectrum at wave-length 6178 Dr. Vogel wrote:—"It must remain for the present undecided whether this band is due to the existence in the Jovian atmosphere of some substance not occurring in our atmosphere, or of some mixture of known gases in proportions different from those prevailing in our atmosphere. It would be quite possible that, with the same proportions of mixture as exist here but with the altered conditions of temperature and pressure which must prevail on Jupiter, the absorption spectrum of the mixture of the gases should undergo the observed variation."

In the spectrum of Saturn's rings, Dr. Vogel found the absorption band in the red very faint or altogether absent. He therefore concluded that the minute bodies composing the rings have little or no atmosphere, and this was confirmed by Professor Keeler. Dr. Vogel's observations of the asteroid Vesta in 1872 led him to suspect the existence of an air-line in its spectrum, but this has not been confirmed. In the spectra of Jupiter's satellites he detected strong bands, indicating the existence of atmospheric envelopes surrounding them. He also detected lines of aqueous vapour in the spectrum of Mars, thus confirming the conclusion of Sir William Huggins. For his researches on planetary spectra, Dr. Vogel received a gold medal from the Copenhagen Academy in 1874.

In 1871 Dr. Vogel studied the Sun, and, by means of Doppler's principle, succeeded in observing the effects due to the solar rotation. While at Bothkamp, also, the distinguished astronomer managed to observe the spectrum of the aurora borealis at its two appearances in that year. He detected several lines, indicating the existence of iron, and he was led to enquire whether iron can exist at the height of the aurora, which is possibly from 400 to 600 miles. However, he was strongly disposed to believe that the auroral spectrum resembled, and was largely a modification of, that of air. Dr. Vogel also observed the spectra of nebulæ, star-clusters, and comets—paying special attention to Coggia's Comet of

1874; and notwithstanding the difficuty of such observations, succeeded in September 1871 in observing the spectrum of lightning. Assisted by Dr. Lohse, he accurately and carefully measured the positions of the brightest lines; and the Bothkamp observations have been fully confirmed ln recent years.

One ot the results of Dr. Vogel's services to science was the foundation by the German Government in 1874 of the Astrophysical Observatory at Potsdam. Dr. Vogel was called to Potsdam as assistant, and therefore resigned his post at Bothkamp. In his new position he continued his researches. He exhaustively investigated *Nova* Cygni, the new star of 1876, observing its spectrum for over a year. He first observed the star on December 5, when its magnitude was 4·5, and noted its spectrum to be crossed by numerous dark shadings. In 1877 he measured the solar radiation by means of a spectral photometer, and arrived at the conclusion that only 13 per cent. of the violet rays pass through the solar atmosphere at the edge of the disc, 16 of the blue and green, 25 of the yellow, and 30 per cent. of the red escaping absorption. It was not, however, in solar astronomy that Dr. Vogel earned his reputation, his observations on the stellar orbs having cast all others into the shade. At length he was appointed to the high post which he was so competent to fill. He was appointed director of the Astrophysical Observatory at Potsdam in 1882.

In 1883 Dr. Vogel published at Potsdam the first spectroscopic star-catalogue, a masterly piece of work, the result of observations made by him at the Astrophysical Observatory from 1880 to 1882, with the assistance of Dr. Müller, of Potsdam Observatory, a son-in-law of Spörer. The catalogue contains details of 4051 stars to the seventh magnitude, embracing a large portion of the sky; and more than half of these proved to be white orbs of Secchi's first type. The work of Dr. Vogel has been completed in different latitudes by Dr. Konkoly at the O'Gyalla Observatory, and by Dr. Dunér at Upsala. Shortly after he became director of Potsdam Observatory, Dr. Vogel visited Vienna and made a series of

direct telescopic observations, mostly on nebulæ, with the great 27-inch refractor of the Imperial Observatory there. The results of his observations were published in 1884.

Assisted by Dr. Scheiner, Dr. Vogel began in 1887 his measurements of the radial motions of the stars. Fifty-one fixed stars bright enough for observation with the 12-inch refractor were selected,* the spectra of the various stars being photographed, and the photographs measured. Some preliminary results were communicated to the Berlin Academy of Sciences in 1888, but the actual results of the observations were not published until 1892. They proved of great interest. It was found that ten miles a second was the average speed of stars in the line of sight, the tendency of the eye being to exaggerate the stellar velocities. The swiftest of the stars examined at Potsdam proved to be *Aldebaran*, with a motion of recession of thirty miles a second. For his magnificent work on the stellar motions, Dr. Vogel received in 1893 the Gold Medal of the Royal Astronomical Society of London. On this occasion Mr. Knobel, the President, remarked:—"The investigation has been conducted with such refined and scrupulous attention to the elimination of errors as renders it worthy of our highest acknowledgment."

During his studies of the stellar motions Professor Vogel made a memorable discovery in connection with the variable star *Algol* or β Persei. It had been suggested by the English astronomer Goodricke, as far back as 1782, that the variability of the star resulted from the partial eclipse of its light by the interposition of a dark satellite. This theory, mathematically confirmed by Professor E. C. Pickering in 1880, was tested spectroscopically by Professor Vogel in 1888 and 1889. It was obvious that if a dark satellite did revolve round *Algol*, the motion of the two globes could be detected by the shifting of the lines in the spectrum. By means of photography, the distinguished astronomer found that before each eclipse *Algol* was retreating from our system, while, on recovering its brightness, it gave signs of rapid approach, proving conclusively

* A list of these is given in Scheiner's "Astronomical Spectroscopy."

that both the star and its dark satellite were in revolution round their centre of gravity, *Algol* suffering partial eclipse only because the plane of the orbit lies in our line of sight. Following up his researches Professor Vogel, assuming that the bright and dark stars are of equal density, arrived at the conclusion that *Algol* is a globe about one and a half million miles in diameter, the satellite equalling the size of our Sun, and the centres of the two stars being separated by about 3,230,000 miles.

Another interesting discovery was announced by Dr. Vogel, April 24, 1890. He found, by photographing the spectrum of *Spica*, the brightest star of Virgo, and examining the photograph microscopically, that the spectral lines were perceptibly displaced, indicating that *Spica* was attended by a dark companion, both stars revolving round their centre of gravity in about four days. The distance between the components was found to be about 6,500,000 miles, a quantity, says Professor Vogel, "far too small to be detected by the most powerful telescopes." Professor Vogel has also discovered other spectroscopic binary stars.

Professor Vogel has made many other studies in spectroscopic astronomy. He has observed the variable stars β Lyræ and Mira Ceti, while his observations on nebulæ and comets have increased an already great reputation. He made a very elaborate investigation of the spectra of meteorites, which he found to be similar to that of comets, thus confirming the discovery of Signor Schiaparelli of the connection between comets and meteorites. Professor Vogel is a prolific writer, and since 1869 has been a regular contributor to the *Astronomische Nachrichten*. In 1895 he published a second paper on the spectra of the planets, based on photographs secured at Potsdam. He confirmed his earlier conclusion that aqueous vapour exists in the Martian atmosphere, a conclusion corroborated by Sir William Huggins, although called in question by Professor Campbell.

In 1874 Dr. Vogel made his first classification of stellar spectra, which was revised and elaborated in 1895. Although

he has modified Secchi's types, his classification improves rather than supersedes the work of the Italian astronomer; nevertheless, he has approached the question from a different standpoint. He concludes that a rational scheme of classification "can only be arrived at by proceeding from the standpoint that the phase of development of the particular body is in general mirrored in its spectrum." Dr. Vogel's classification is now generally adopted, and a brief discription of it may be given here. The first type is divided by Professor Vogel into three classes. In the first, designated Ia, the metallic lines are "very faint and fine," and the hydrogen lines conspicuous: *Sirius* and *Vega* are examples of this class. In Ib, no hydrogen lines are visible, while in Ic the lines of hydrogen are conspicuous as bright lines. This class includes the so-called "gaseous stars." In 1895 Dr. Vogel separated the stars of Ib from the first type. These stars are characterised by lines of helium, and are represented by *Rigel* and other stars in Orion. They are often found in connection with nebulæ, and are probably the most youthful orbs. They are known both as "Orion stars" and "helium stars."

Dr. Vogel divides the solar type into two classes. Class IIa is represented by such stars as the Sun, *Capella*, *Arcturus*, *Aldebaran*, etc., and characterised by numerous metallic lines. The lines of hydrogen are also conspicuous, but not so striking as in Ia. Under IIb Dr. Vogel includes the gaseous Wolf-Rayet stars. He divides the red stars into two classes, the first (IIIa) represented by *Betelgeux* and the second by the carbon stars, which were originally designated by Secchi as of the fourth type. The temperature of stars of Dr. Vogel's Classes IIIa and IIIb is so far reduced as to allow the formation of chemical compounds in their atmospheres. Many stars of this class are long-period variables.

In the opinion of Dr. Scheiner, Dr. Vogel's colleague at Potsdam, "one of the most important results of the spectroscopic surveys which have been carried out by D'Arrest, Vogel, Dunér, and Pickering, is the fact that hardly a spectrum has been found which cannot be brought under Vogel's classifica-

tion. This is by no means because the classification provides for all possible combinations of spectra, for we can readily imagine new combinations. . . . The fact that such do not occur must be regarded as bearing important testimony to the practical correctness of the classification." These investigations on stellar classification naturally prepared the way for Dr. Vogel's views on the subject of stellar evolution. He regards Sirian stars as the hottest and youngest orbs. Solar stars are viewed by him as having wasted much of their store of radiation, while he regards red stars similar to *Betelgeux* as "effete suns hastening rapidly down the road to final extinction." Dr. Vogel is of opinion that the red stars of Secchi's fourth type are like those of the third type, dying suns. Both types represent alternative roads for stars of the solar type in their decline into dark stars. Thus, our Sun may decline into either an orb similar to *Betelgeux* or to 19 Piscium. Professor Vogel's theory of stellar evolution is less complicated and more comprehensive than that of Sir Norman Lockyer, and similar views are held by Sir William Huggins, Professor Dunér, Professor E. C. Pickering and Mr. J. E. Gore.

In the course of his observations on the new star which appeared in Auriga in 1892, Professor Vogel reached the conclusion that the outbreak was due to the collision of a dark star with a system of planets surrounding a worn-out sun, the second outbreak of light being due to an encounter with an out-lying planet.* In 1901 Professor Vogel studied exhaustively the new star which appeared in Perseus. He determined its radial motion, which he found to be twelve miles a second in a direction away from the Sun; in 1900 he investigated the system of *Capella*, and finds its mass to be over twice that of the Sun, the distance between the components being about 53,000,000 miles; and in 1901 he fixed the period of the spectroscopic binary star *Mizar* as twenty days. It would take too long to describe in detail each of Professor Vogel's researches, which have given him a place

* This hypothesis is not in accord with that of Sir William Huggins or with that of Professor Seeliger, which is described in a later chapter.

among the greatest living astronomers. It is satisfactory to see that his services to science have been appreciated both in Germany and elsewhere. He is a member of many of the scientific societies of Europe and America. He received the Valz Prize from the French Academy of Sciences in 1891, and the Henry Draper Medal from the National Academy of Sciences in Washington in 1892, the Gold Medal of the Royal Astronomical Society in 1893, and in 1895 the Prussian Order *pour le Mérite.*

Professor Vogel's remarkable investigations and extraordinary discoveries place him among the greatest of astronomers. He has surveyed the entire field of astronomical research, from the fixing of the position of a star cluster and the observation of the spectrum of Mercury to the progress of evolution in the stellar depths. The accuracy with which Dr. Vogel has conducted his observations seems almost incredible. But for his skill and perseverance he could not, by observing the displacement of spectral lines, have so accurately measured the sizes and motions of the stars. With the aid of his marvellous instruments, he has been enabled to measure the size and mass of bodies which cannot, and never will, be revealed to human sight; he has fixed the periods of revolving stars indivisible by even the most powerful telescopes; and he has measured the almost imperceptible velocity of stars plunged in the depths of space. Dr. Vogel may be truly described as the pioneer of "the astronomy of the invisible."

Sir David Gill.

In practical astronomy, the most fascinating and difficult branch of research, is to-day, as seventy years ago, the measurement of stellar parallax. It is this branch of astronomical science which gives us the grandest view of the Stellar Universe reached by the precise determination of a very small displacement—a combination of the infinitely little and the infinitely great. It is to measurement of stellar parallax that Sir David Gill, our greatest Scottish astronomer, has devoted his attention.

David Gill was born in Aberdeen on June 12, 1843. His father was David Gill, an Aberdeen gentleman; and the future astronomer received his education in Marischal College, Aberdeen. He became at an early age devoted to astronomy, and after working in the small observatory of King's College, he erected a private observatory in the garden of his father's house. Five years later he took part in the foundation of Lord Lindsay's private observatory at Dunecht, and received the appointment of director in 1873. The following year he organised Lord Lindsay's expedition to Mauritius for the observation of the transit of Venus in 1874, with a view to accurately measuring the solar parallax. At the same time he executed a measurement of the distance of the Sun by means of the asteroid Juno. While on this expedition he was requested by the Khedive to undertake the measurement of the first baseline of the geodetic survey of Egypt.

In 1876 Mr. Gill resigned his position in the Dunecht

Sir David Gill.

(Photo. by Elliot & Fry. London.)

Observatory in order to start on an expedition to the island of Ascension for the purpose of measuring the solar parallax by observations on the planet Mars with Lord Lindsay's heliometer, a method differing considerably from that of the transit of Venus. Instead of the parallax being measured by different astronomers, thousand of miles apart, as in the case of the transit of Venus, the observations can be made by one observer, using one instrument, and measuring the parallax of Mars with reference to neighbouring stars. During the memorable opposition of Mars in September 1877, when Professor Asaph Hall discovered the satellites, and Professor Schiaparelli detected the canals, Dr. Gill was employed in Ascension measuring the solar parallax by means of the red planet. "Unlike the projects for observation of the transit of Venus, which began so hopefully and ended in disappointment," writes Professor H. H. Turner, "Gill's expedition began with disaster and ended successfully. The instrument he was to take with him to Ascension was constructed for European latitudes, and, as he thought it possible that when set up in a tropical latitude it might not work well, he set it up for trial in the rooms of the Royal Astronomical Society some little time before starting. His doubts proved only too well founded. Scarcely had the instrument been erected, as it would be in Ascension, when it overbalanced and came crashing down on its delicate eye end, practically a wreck." In due time, however, Dr. Gill had the instrument repaired, and he arrived safely in Ascension on July 13, 1877. Four days later the observatory was erected, but he changed its site and re-erected the heliometer in a part of the south-western extremity of the island now known as "Mars Bay," * where from August 4 until October 4 a large number of observations were made. He successfully measured the parallax of Mars, and from that deduced the distance of the Sun, which he concluded to be 93,080,000 miles. For these investigations Dr. Gill received in 1882 the Gold Medal of the Royal Astronomical Society. The President, the late Dr. Hind, remarked on this occasion—"As a piece of

* Monthly Notices R.A.S. Feb. 1882.

admirable work, carried to its conclusion with the unremitting energy and great zeal which Mr. Gill has always evinced, I believe you will concur in the opinion of your Council that he has well deserved the award of the Medal."

In 1879 Dr. Gill was appointed Her Majesty's Astronomer at the Cape of Good Hope, in succession to Mr. E. J. Stone, who had accepted the position of Radcliffe Observer at Oxford. Dr. Gill's first work was the reduction and publication of previous observations. From 1881 he was engaged in that fascinating but difficult branch of astronomical research—the measurement of star distance. Dr. Gill's work was a considerable advance on previous results. In conjunction with Dr. Elkin, a young American astronomer—now director of the Yale College Observatory—he determined, with Lord Lindsay's heliometer, the parallaxes of nine stars. He found the distance of α Centauri to be greater than previous estimates had made it, while *Sirius* turned out to be situated at only half the distance that had been previously assigned to it. *Canopus*, on the other hand, was discovered to be situated at an almost immeasurable distance from the Solar System, proving it to be of gigantic size, and to be, in all probability, one of the largest stars in the Universe.

In 1887 Dr. Gill commenced a second series of observations on southern stars with the aid of a 7-inch heliometer, constructed under his directions in Hamburg. The results of both his investigations showed the first magnitude star β Centauri to have a "negative" parallax, that is to say, the small comparison stars used in the investigation turned out to be as near, or nearer, to the Solar System than the bright star itself, implying β Centauri to be a sun of immense size. For *Rigel* in Orion Dr. Gill also found a negative parallax, showing the star to be certainly very large, and the comparison stars to be very small. The observations made with the larger heliometer fully confirmed those with the smaller, and with both instruments he determined the parallaxes of *Sirius*, *Canopus*, *Rigel*, α Centauri, *Achernar*, β Centauri, α and β Crucis, *Spica*, *Fomalhaut*, *Antares* and α Gruis; as well as a number of small

stars having large proper motions. Dr. Gill's conclusions regarding the Stellar Universe, from observations on parallax, were stated by him in 1902 as follows:—

1. "The absolute amount of light radiated by a single star varies in the 22 stars observed from about 10,000 times to less than $\frac{1}{300}$ part of that given off by our Sun, so that indeed 'one star differeth from another star in glory.'

2. The absolute velocities at right angles to the line of sight vary for the 22 stars from $2\frac{1}{2}$ to 70 miles per second—velocities which are of the same order of magnitude as the velocities in the line of sight determined by spectroscopic methods.

3. The average parallax of a star of the first magnitude is $\frac{1}{10}$ of a second of arc.

4. The Sun, if placed at the average distance of the first magnitude stars, would appear to us as a star of the fifth magnitude."

The appearance of the great comet of September 1882 marked the introduction of photography to the Cape Observatory. With the aid of the camera of a local photographer, strapped to the equatorial telescope of the observatory, he secured some remarkably good photographs of the comet, and was struck with the number of individual stars shown on the background. A new idea was suggested to his mind. For some time past he had contemplated the extension of the great "Durchmusterung" of Argelander and Schönfeld, of the Bonn Observatory, to the south pole, and the photographs of the comet suggested that the positions of the stars could be determined by means of photography with equally great accuracy and much less labour than by the older method. In 1885, accordingly, the observations commenced, and in four years were completed. Half a million stars are represented on the plates of the "Cape Photographic Durchmusterung." The measurement of the plates was undertaken by Professor Kapteyn, of Groningen, the eminent Dutch astronomer, whose life and work is described in another chapter. In 1900 the great catalogue, the combined work of Dr. Gill and Professor Kapteyn, was completed and published under the name of the *Cape Photographic Durchmusterung.*

On June 4, 1886, Dr. Gill, in conjunction with the late

M. Mouchez, director of the Paris Observatory, proposed that a congress of astronomers should meet at Paris to arrange for the construction of a photographic chart of the entire sky, embracing all stars down to the eleventh magnitude. Dr. Gill was elected senior member of the permanent committee for the accomplishment of the work, and attended the meetings in Paris in 1887, 1891, 1893, 1896, and 1900. The largest of the eighteen zones into which the work was divided was assigned to the Cape Observatory, under Sir David Gill's direction. The work of the observatory is now far advanced towards completion.

Another of Dr. Gill's important works was that of determining the Sun's distance from observations on some of the Asteroids, carried out at the Cape Observatory in 1888 and 1889. The principle was the same as that of observations on Mars, but Dr. Gill considered that the positions of points of light like the Asteroids could be determined with much greater accuracy than that of a planet like Mars, which shows a measureable disc. The Asteroids chosen for the investigation were Iris, Sappho, and Victoria, and from observations of the latter, Dr. Gill fixed the distance of the Sun as 92,700,000 miles. At the opposition of Iris an almost identical result was reached. In 1891 a series of observations on Jupiter's satellites were made with the Cape heliometer in order to determine more exactly the mass of Jupiter. Instead of measuring the positions of the satellites relative to the planet, Dr. Gill measured them relative to each other. The mass of Jupiter which he derived from these observations agreed almost exactly with a result arrived at by Professor Newcomb from the perturbations of Jupiter on asteroids and comets. Since the appearance of the comet of September 1882, celestial photography has been actively prosecuted at the Cape Observatory. Dr. Gill has obtained photographs of star-clusters and nebulæ, among them the cluster ω Centauri and the nebula surrounding η Argus, the wonderful variable star. His studies of the Milky Way led to his discovery in 1891—independently of Professor Pickering and Professor Kapteyn—that Sirian

stars show a tendency to crowd towards the plane of the Galaxy.

It is somewhat remarkable that the astronomers who have laboured in South Africa have devoted much attention to geodetic measurements. Lacaille, Fallows, and Maclear each measured an arc of the meridian. Following the example of his predecessors Sir David Gill has executed several surveys and was chosen to determine the boundary between British Bechuanaland and German South-West Africa. The geodetic survey of Cape Colony and Natal has also received much attention from him.

Dr. Gill has received many honours in reward for his services to astronomy, and only the chief among these can be mentioned here. In 1896 he was created C.B., and in 1900, when on a visit to England, Knight Commander of the Bath. In 1875 he received from the Khedive the Medjidie Order, and in 1881 the Valz Prize of the French Academy of Sciences for his investigations on the solar parallax. For distinguished services to astronomy Sir David Gill received, in 1900, the Watson Gold Medal of the National Academy of Sciences, Washington, and in 1903 the Bruce Medal of the Astronomical Society of the Pacific. In November 1903 he received the Royal Medal of the Royal Society, of which he was elected a Fellow in 1883. In 1881 and 1884, respectively, he was made L.L.D. of Aberdeen and Edinburgh Universities. A large number of other honours have been conferred on the distinguished Scotsman.

Although Sir David Gill is a practical astronomer, he has taken much interest in astrophysics. For some time, indeed, it appeared as if the work of the Cape Observatory was to be given exclusively to practical astronomy; but in 1894 the late Mr. McClean, of Tunbridge Wells, announced his intention of presenting to the observatory a complete astrophysical outfit. In 1898 the "Victoria telescope" arrived at the Cape, but the object-glass was found defective, and had to be corrected. On September 19, 1901, Sir David Gill unveiled the inscription stone of the telescope, and delivered an interesting address on

astrophysics. Sir David Gill took an active part in the foundation of the South African Association for the Advancement of Science, and while on a visit to London in 1900, he was present at a meeting of the Council of the British Association for the purpose of discussing the desirability of holding one of their meetings in South Africa. On the foundation of the new Association, Sir David Gill was selected to be the first President, and he delivered his first Presidential Address on April 27, 1903. At the close of his address he very truly remarked that "science knows no nationality, and forms a meeting-ground on which men of every race are brethren, working together for a common end—and that end is truth."

Sir David Gill's researches on stellar parallax are the most exact yet reached. His researches have proved that there are all classes of suns—that suns of gigantic size and very small suns exist in space, and that the star which we call the Sun occupies a very humble position in the Universe. Sir David Gill's studies in astronomy show us more forcibly than ever the vast scale on which the Stellar Universe is built. Scotland may well be proud of so earnest and devoted an astronomer. It is a remarkable fact that Scotland, in comparison with England, France, Germany, Italy, or the United States, has produced very few students of the heavens. Sir David Gill, as Scotland's leading modern astronomer, holds an honoured and exalted position in the annals of Scottish science.

John Ellard Gore.

John Ellard Gore.

A STRIKING proof of how much may yet be done for the progress of astronomy by means of very moderate instruments is afforded by the life of the distinguished Irish astronomer who forms the subject of this chapter. By observations with small telescopes, with binoculars, and even with the naked eye, Mr. J. E. Gore has added considerably to our knowledge of the heavens, and especially of variable stars, by his discoveries of these objects, his persistent study of their light-changes, and his careful observations of suspected variables. Unaided by either influence or facilities—at first a mere amateur in astronomy—Mr. Gore, by his constant and attentive scrutiny of the starry heavens, has placed himself among the most distinguished of modern astronomers.

John Ellard Gore was born at Athlone on June 1, 1845. Educated privately and at Trinity College, Dublin, he went to India in 1868, serving in the Government Public Works Department as assistant engineer on the Sirhind Canal, in the Punjab. While so employed his attention was drawn to astronomy. He began to observe the heavens with telescopes of three or four inches aperture, and with the naked eye and binocular. With the 3-inch telescope, mounted on a round brick pillar about 5½ feet in height, Mr. Gore made many valuable observations. In the clear air of the Punjab he studied exhaustively double and variable stars. His observations, valuable especially in regard to suspected variables, are of great use in noting the exact brilliancy of the stars observed

by him in the seventies. His observations were published in a little book entitled "Southern Stellar Objects for Small Telescopes," which appeared in 1877.

In September 1872, Mr. Gore, observing with the naked eye at an altitude of over 6000 feet in the Himalayas, detected a remarkable vacuity in the Milky Way in Cygnus, not represented in Proctor's atlas. He also noticed a dark rift passing across the Galaxy between the stars ξ and ρ Cygni. In March 1873 he detected a faint extension of the Milky Way through part of Orion. In December 1874 he observed the transit of Venus. "At Ingress," he writes, "I distinctly saw the disc of Venus outside the Sun's limb, owing to a faint ring of light which surrounded it, caused probably by refraction through the planet's atmosphere. While the planet was on the Sun I could not see any light on the disc, nor any trace of a halo round the planet. . . . No trace whatever of a satellite was visible in my instrument."

Mr. Gore returned to Ireland in 1877 on a two years' furlough, and in 1879 he definitely retired on a pension from the Government service. He was now able to devote his time to the pursuit of his favourite science. In 1882 he observed the transit of Venus in the west of Ireland with his 3-inch refractor. He presented to the Royal Irish Academy in 1884 a "Catalogue of Known Variable Stars," containing references to 190 stars, augmented to 243 on the revision of the catalogue four years later. Mr. Gore also published a "Catalogue of Suspected Variable Stars." Since 1879 he has paid great attention to binary stars, and has computed the orbits of twenty of these objects. For ζ Sagittarii, a southern binary, he computed in 1886 an orbit with a period of 18 years. For 70 Ophiuchi in 1888 he found 87 years; for Sirius in 1889 he found 58½ years; and for β Delphini he finds 30 years. His calculations are very reliable, and he has been one of the most successful of binary star computers. He has also studied the subject of the inclination of the orbits of binary stars. In 1888 he published in "Planetary and Stellar Studies" the results of his studies of their orbital inclinations. He finds that the planes of 28 out of 48 double

star orbits examined by him are at right angles to the plane of the Galaxy. He presented to the Royal Irish Academy, June 9, 1890, a "Catalogue of Computed Binaries," containing reference to fifty-nine stars. Of especial interest are his calculations on the masses of binary stars. Some of these calculations prove the existence among the stars of what may be called "sun-like planets." In the case of δ Cygni, of which the components are respectively of the third and eighth magnitudes, he points out, the primary is one hundred times brighter than the companion. If of the same surface brilliancy, the ratio of the diameters of the two stars are as ten to one, "about the same proportion which exists in the case of the Sun and Jupiter, and we may perhaps consider the companion as a giant planet in the sun-like stage of its existence."

It must be admitted that it is in the study of variable stars that Mr. Gore has earned his reputation. In addition to persistent observations both in India and in Ireland, he has discovered four variables, and has practically disclosed the variability of many other stars. In 1884 he discovered a star closely south of ρ in the constellation Cygnus. It is now known as W Cygni, and varies from the fifth and sixth magnitude at maximum to the sixth and seventh magnitude at minimum, the mean period being 131 days. Its spectrum is of the third type and has been described by Professor Dunér as of "extraordinary beauty." In 1885 Mr. Gore discovered his second variable, S Sagittæ, which he found with a binocular field-glass. It varies in a period of 8 days, 9 hours, 11 minutes, and 48 seconds from the fifth to the sixth magnitude.

On the evening of December 13, 1885, at 9.20 P.M., Mr. Gore, while observing with a binocular the small stars in the northern portion of Orion, detected a reddish star of the sixth magnitude near χ Orionis, which was not mentioned by Lalande, Harding, Heis, or John Birmingham. He at once suspected it to be a temporary star, and indeed for some time it was known as Nova Orionis. The following day he sent news of his discovery to Dr. Copeland at Dunecht, who confirmed the observation and examined the star with the

spectroscope, recording for it "a beautiful banded spectrum of the third type, seven dark bands being readily distinguished with the prism." Meanwhile the new star steadily faded, and in July 1886 was only of the twelfth magnitude. In the autumn its light increased, and it reached a maximum on December 10. Further observations showed it to be a long-period-variable, with a period of about 375 days. It is now designated U Orionis.

In 1890 Mr. Gore discovered X Herculis, another variable, with a period of about 92½ days. His observations of 7 Arietis from 1875 to 1886 show it to be probably variable, while his studies of λ Draconis show in his own words, "decided fluctuations to the extent of nearly one magnitude." In 83 Ursæ Majoris, *Denebola* (β Leonis) and μ Cephei, he has also detected inconstancy of light. Mr. Gore has paid much attention to the distribution of variable stars. In "The Worlds of Space" (1894), he points out that few variables show any appreciable parallax, and few of them have any considerable proper motion. To explain this, he suggests that the Sun and Solar System is situated in a region devoid of variable stars, an inference strengthened by the fact that the stars with measurable parallaxes are constant in light. Mr. Gore finds a tendency of the variable stars to cluster into groups. "Thus, in and near the constellation Corona Borealis there are five; near Cassiopeia's chair, five. In Cancer there are four in a limited area. Near η Argus there are several, and in a comparatively small region in the northern portion of Scorpio there are no less than fifteen variable stars."

In 1888 Mr. Gore published his first popular work, "Planetary and Stellar Studies," in which he recorded many observations, and which contained two suggestive chapters "On the Infinity of Space" and "On the Absolute Dimensions of a Star Cluster." In "The Scenery of the Heavens" (1890), he dealt with the question of the construction of the heavens at considerable length. About this time he published several works, "Astronomical Lessons" (1890), "Star Groups" (1891), "The Astronomical Glossary" (1893), "The Visible

Universe" (1893), a discussion of the various theories of the origin and construction of the heavens. In 1894 he published his translation of M. Flammarion's "Popular Astronomy," and in the same year "The Worlds of Space," which consists mainly of miscellaneous papers and articles, some of them on the habitability of the planets. Mr. Gore contributed the section on "The Sidereal Heavens" to the "Concise Knowledge Astronomy" (1898). His most recent works are, "The Stellar Heavens" (1903), and "Studies in Astronomy," which appeared in 1904.

The conclusion arrived at by Proctor and confirmed by Signor Schiaparelli, that the brighter stars show a tendency to aggregate on the Milky Way, has been fully verified by the work of Mr. Gore. He examined the positions of all the brighter stars in the northern and southern hemispheres. He found that of 32 stars brighter than the second magnitude, twelve lie on the Milky Way or "on faint nebulous light connected with it." Of those brighter than the third magnitude 33 stars out of 99 lie on the Galaxy, and of those brighter than the fourth 73 out of 262. Now the area covered by the Milky Way does not exceed one-seventh of the entire heavens and in Mr. Gore's own words "the number of brighter stars is considerably more than that due to its area." He also made an enumeration of all the stars in the atlas of Heis which lie on the Galaxy and found the percentage of stars on the Milky Way "one and a half times that due to its area." Mr. Gore went even further in his enumerations. In order to include stars of the eighth magnitude, he made an examination of the stars to that magnitude on the charts constructed by Harding, and found "a marked increase in the number of stars where the zone crossed the Milky Way." Mr. Gore's valuable and laborious investigations have thus shown that stars of each individual magnitude, taken separately, tend to aggregate on the Galaxy.

Another fact pointed out by Mr. Gore is the apparent connection between the lucid stars and the nebulous light of the Galaxy. He points out that the stars α, β, γ, η, and κ of

Cassiopeia, and ι, κ, and λ of Andromeda, mark respectively two luminous spots of galactic light. The edge of a dark space in a luminous region is marked by the stars, δ, ϵ, and ζ Cephei, while an offshoot from the Galaxy is distinguished by the stars, ϵ, ξ, ζ, and o Persei, "The remarkably bright oblong spot in Cygnus includes the stars, β, γ, η, ϕ, the variable χ Cygni, and other smaller stars;" while a brilliant portion of the Galaxy envelopes the stars forming Sagitta, and a fainter offshoot includes Delphinus. "The stars 67, 68, and 70 Ophiuchi lie at the extremity of a luminous spot on the broken branch in Ophiuchus;" while the stars λ, 6, 9, and 12 of Aquila are ranged along the northern border of a bright spot of galactic light in Scutum. On October 26, 1889, Mr. Gore noted as follows—"North of α Cygni, and near ξ and ν Cygni, the nebulous light of the Milky Way seems to cling round and follow streams of small stars in a remarkable way; numerous small 'coal sacks' and rifts are visible, in which comparatively few stars are to be seen in the binocular." This remarkable observation—a brilliant example of what can be done by means of the binocular—has been fully confirmed by the photographs of Professor Max Wolf.

In his work, "The Worlds of Space," Mr. Gore discusses the plurality of worlds, and, in regard to the Solar System, he believes that Venus is the planet most likely to be inhabited by intelligent beings. Mr. Gore considers, however, that life is not so far advanced as on this planet. He is of opinion that the Sun is cooling down, and that in the course of ages life will die out on our planet, and "Venus will probably form the theatre of life. . . . Later still, in the march of time, life will die out on Venus also, and then Mercury will become cool enough—even at the centre of its sunlit side—to be inhabited by animal life." Mr. Gore then proceeds to discuss the habitability of planets revolving round other suns. He concludes that "the stars, at least those with spectra of the solar type, form centres of planetary systems somewhat similar to our own." After an elaborate discussion as to the conditions necessary for the maintenance of life, he computes the probable number of

inhabited worlds in the Universe. He estimates the number of stars in the visible universe at 100,000,000, 10,000,000 being of the solar type. Even allowing only one in ten of these to have *one* habitable planet revolving round it, he finds a total of 1,000,000 habitable worlds, and this estimate is probably a very modest one.

Mr. Gore is one of the highest authorities on the great question of the structure of the Sidereal System. In his "Planetary and Stellar Studies" he suggested a possible thinning-out of the ether of space at the boundaries of our Universe, which would have the effect of cutting off from our view the light of external universes. In "The Scenery of the Heavens" he speculates on the origin of the Milky Way, considering it to be the remains of a vast "vortex-ring" which, originating in a great nebulous mass, has partially broken up. "After the isolation of this vortex-ring in the ether, its disintegration could, of course, be caused only by the mutual attractions of its component members, and from the general appearance of the Milky Way it seems highly probable that its present condition is the result of gravitation between its members."

In "The Visible Universe," an elaborate volume on the origin and construction of the heavens, Mr. Gore discusses the various theories of the constitution of the Milky Way advanced by Wright, Kant, Lambert, Herschel, Struve, and Proctor. After a profound discussion of the views of these and other thinkers, he arrives at the conclusion that our Universe is limited in extent, and brings forward evidence to support this conclusion. "It may be proved mathematically," he writes, "that, supposing the number of stars infinite and equally distributed through infinite space, if there is no extinction of light in the ether, the whole heavens should shine with the brightness of the Sun. Such is clearly not the case. On the clearest nights the amount of light afforded by the stars is, on the contrary, very small, and the comparative blackness of the background on which they are scattered is sufficiently obvious. The number of the *visible* stars cannot therefore be infinite."

Mr. Gore also points out that the hypothesis of light-extinction is untenable, and that the limited number of the visible stars is only to be explained by the theory "that all the stars, clusters and nebulæ visible in our largest telescopes form one vast system, which constitutes our visible Universe."

Mr. Gore supposes, however, that our finite Universe is not the only one and that there exist other universes at an immense distance from our system. He regards the Solar System as a system of the first order, the Galaxy of the second, and the invisible universes which he supposes to exist as the third, and so on to the fourth and higher orders. In "The Stellar Heavens" he says: "But we need not go further than the third order, for, if light would probably take millions of years to reach us from an external universe of the second order, surely the altogether inconceivable distance of systems of the third order would sufficiently account for their light not yet having reached us, although travelling towards our Earth for possibly billions of years." In "The Visible Universe" Mr. Gore makes a calculation of the possible distance of an external universe of his second order. Assuming the distance of the nearest external universe from our Galaxy as proportional to that separating the Sun from α Centauri, he arrives at the amazing conclusion that the distance of the nearest Galaxy is 520,149,600,000,000,000,000 miles, a distance which light, with its amazing velocity of 186,000 miles a second, would take almost ninety millions of years to traverse. He suggests that either a thinning-out of the ether occurs at the bounds of our Universe, or an extinction of light takes place, cutting off from our view these external Galaxies. He sums up with the words:—"Although we must consider the number of *visible* stars as strictly finite, the numbers of stars and systems really existing, but invisible to us, may be practically infinite. Could we speed our flight through space on angel wings to a distance so great that the interval which separates us from the remotest fixed star might be considered as merely a step on our celestial journey, what further creations might not then be revealed to our wondering vision. Systems of a higher order might there be unfolded to our view,

compared with which the whole of our visible heavens might appear like a grain of sand on the ocean shore, systems perhaps stretching out to infinity before us, and reaching at last the glorious 'mansions' of the Almighty, the Throne of the Eternal."

On the evening of February 22, 1901, at 11.40, Mr. Gore observed "a great new star in Perseus, between β Persei and δ Persei; preceding, a little north of ν Persei. Much brighter than α Persei and about equal *Pollux*." The discovery was made independently by Mr. Gore twenty-two hours after the star was found by Dr. Anderson.* Until November 16, 1901, he made many valuable observations on the new star on every available evening at first with the naked eye, and, when the star had faded considerably, with the binocular. On February 24, at 10.45 P.M., the star was estimated equal to *Capella*, but two days later had commenced to fade. By April it was of the fifth magnitude, and in August, September, and October, 1901, had fallen to the sixth, the decline of light being carefully watched by Mr. Gore. The results of Mr. Gore's observations were published in the *Monthly Notices* of the Royal Astronomical Society for December 1901.

To the irregular variable star, *Betelgeux* or α Orionis, Mr. Gore has given much attention. In December 1887, he observed a well-marked minimum of light, the star being not brighter than *Aldebaran*, which it usually exceeds in brilliance. On October 16, 17, and 26, 1902, Mr. Gore found *Betelgeux* to be unusually bright. It surpassed in brilliance *Procyon* and was equal to *Capella*. Mr. Gore has recently been investigating what he calls the "Secular Variation of Starlight," to which subject he devotes a chapter in his recent volume, "Studies in Astronomy." In his examination of Al-Sufi's "Description of the Fixed Stars," which was written in the tenth century, and which included the magnitudes as given by

* The star was discovered independently of Mr. Gore and Dr. Anderson by Mr. Gregg at Hastings, Mr. Laursen-Nordvig in Denmark, Herr Grimmler at Erlangen. M. Borisiak, a young Russian astronomer, discovered it at Kiev before it had been seen elsewhere.

Hipparchus and Ptolemy, he noticed a number of cases in which a star seems to have increased or diminished in brillance. Mr. Gore points out that, although two thousand years is a short period in the life of a star, it is probable that some perceptible changes may have taken place since the time of Hipparchus.

In a letter to *Knowledge*, in December 1903, Mr. Gore writes: "The idea has occurred to me that possibly the phosphorescent glow of the gaseous nebulæ may be due to the presence of radium in the gaseous state; in other words, that the unknown element 'nebulium' may be identical with radium." There has long been a difference of opinion among astronomers as to the nature of the "chief nebular line," and Sir Norman Lockyer based his meteoritic hypothesis on its supposed identity with magnesium. Mr. Gore's idea is worthy of consideration.

Mr. Gore is a Fellow of the Royal Astronomical Society, a member of the British Astronomical Association and of the Société Astronomique de France; a member of the Royal Irish Academy, honorary member of the Welsh Astronomical Society, and a Corresponding Fellow of the Astronomical Society of Canada. From 1890 until 1899 he was Director of the Variable Star Section of the British Astronomical Association. Mr. Gore is a frequent contributor to the *Monthly Notices* of the Royal Astronomical Society and to *Knowledge*, *The Observatory* and other scientific periodicals. His works are famed for their accuracy and for the religious spirit which distinguishes them.

Mr. Gore has gained for himself a unique position in astronomical science. While he is one of the greatest living students of the heavens, he has never held any official astronomical appointment, and owes almost nothing to the universities. He is in many respects a non-telescopic observer; at all events, he has shown what can still be done with small telescopes and even with the naked eye. His researches on the construction of the heavens are elevating in the extreme, and convey to the

mind an idea of the infinity of space. His astronomical investigations are distinguished by a noble appreciation of the vastness of the Universe, and an earnest desire to reach the truth.

George Howard Darwin.

THE evolution of the Solar System forms one of the most interesting of the questions presented by modern astronomy. It is to this branch of astronomical thought that Professor G. H. Darwin of Cambridge has made his most striking contributions. While adopting Laplace's theory of the development of the Solar System as a whole, he has shown that as a consequence of the remarkable effects of tidal friction, the evolution of the Earth and Moon has been probably unique in the Solar System. Although something was before known of tidal friction, it was not supposed to have played such a leading part in the formation of celestial systems. Professor Darwin's exhaustive studies of the tides show how much may be learned in astronomy from what appears to be one of the most ordinary phenomena, supposed to have been exhaustively investigated many years ago—the ebb and flow of the ocean.

George Howard Darwin is the second son of Charles Darwin, the great biologist. Born at Downe, in Kent, on July 9, 1845, he received his education under the Rev. Charles Pritchard, afterwards Savilian Professor of Astronomy at Oxford. In October 1864, when nineteen years of age, the future mathematician entered Trinity College, Cambridge, where he graduated in 1868. He afterwards pursued the study of law and became a barrister in 1872; but his mind evidently lay in another direction, and he returned in 1873 to Cambridge, where he began his mathematical and astronomical studies. In 1876 he contributed a paper "On the Influence

George Howard Darwin.

(Photo. by Maull & Fox, London.)

of Geological Changes on the Earth's Axis of Rotation" to the Transactions of the Royal Society, of which he was elected a Fellow in 1879.

Before describing Mr. Darwin's researches regarding the tides, it is well to refer to his attempts to measure the lunar attraction on a pendulum, made with the assistance of his brother, Mr. Horace Darwin, in 1879. A pendulum was suspended by two wires and was hung inside a copper tube, just wide enough to allow the pendulum to oscillate without touching its sides. At the bottom of the tube was hung a small mirror suspended by two silk fibres, and opposite the mirror was placed a lamp. "A slight rotation of the mirror," writes Professor Darwin, "corresponds to an almost infinitesimal motion of the pendulum, and even excessively small movements of the mirror are easily detected by means of the reflected image of the light. . . . The image of the movable gas-jet was observed by a fixed telescope." The copper tube was supported on three legs resting on a block of stone a ton in weight, and this stood in a north room in the laboratory at Cambridge. The position of the gas-jet could be determined to within one-twentieth of an inch; and so refined was the method of observing that had the pendulum moved though even one-millionth part of an inch the motion could have been detected. Although the instrument was quite delicate enough to measure the lunar attraction, Mr. Darwin failed in his intention, as a result of the pendulum changing its position owing to disturbances of a completely different nature.

In 1882 Mr. Darwin assisted Sir William Thomson, now Lord Kelvin, in the preparation of the second part of a new edition of "Thomson and Tait's Natural Philosophy." On January 16, 1883, he was appointed Plumian Professor of Astronomy and Experimental Philosophy in the University of Cambridge, in succession to Professor Challis. Two years later he became a Member of the Council of the Meteorological Office. In 1883 he read before the British Association at its meeting at Southport a paper on the "Harmonic Analysis of Tidal Observations." Throughout his scientific career, Professor

Darwin's principal object of study has been the tides. He has made the subject peculiarly his own. Although some remarkable speculations on tidal friction had been made by Kant and by Delaunay over a century later, the subject had never been exhaustively investigated. Professor Darwin began his researches into the evolution of the Earth-Moon system in 1877. On December 18, 1879, he communicated to the Royal Society the results of his first studies in this line of research. The paper was followed by others in 1881 and 1882. In his work, "The Tides and Kindred Phenomena in the Solar System," which was published in 1898, he gives a description of the conclusions which he has arrived at regarding tidal friction.

Professor Darwin finds that the tides act upon the Earth as a brake does upon a machine. They tend to retard the rotation of the Earth. As a consequence, the day is growing longer, and, as the tidal wave is constantly pulling the Moon forward, the Moon's orbit is becoming enlarged, and consequently the period of its revolution around the Earth is gradually growing longer. At present the day is about twenty-four hours long, and the month about twenty-seven days. The day, however, will be lengthened at a more rapid rate than the month, and in the remote future the day and month will both last fifty-five of our present days. The Moon will revolve round the Earth in the same period that the Earth rotates on its axis, and the two bodies will perform their circuit round the Sun as if united by a bar.

Not only can we foresee the future of the Earth-Moon system, but we can also read the past. According to Professor Darwin's theory, the Earth, in the remote past, was probably rotating on its axis in a very short period, between three and five hours. The Moon must then have been much nearer us than it is now, and was probably revolving round its primary in the same period that the Earth took to rotate on its axis. The two globes, then gaseous, must have been revolving almost in actual contact. Had the month been even a second shorter than the day, the Moon must inevitably have fallen

back on the Earth. As it was, the condition of affairs could not endure. The condition of the Moon resembled that of an egg balanced on its point. The Moon must either recede from the Earth or fall back upon it. The solar tide here interfered, and caused the Moon to recede from its primary until it reached its present distance of 239,000 miles.

It needs only one step more to complete Professor Darwin's theory of the evolution of the Earth-Moon system. The fact that the Earth and Moon were, at a remote epoch, almost in contact, suggests that they were originally *in* contact. In other words, the Moon originally formed part of the Earth, which, in consequence of its short rotation period, and probably also owing to the interference of the solar tide, split into two portions, and the smaller of these now forms the Moon. It is likely that the matter now forming the Moon was detached from the Earth in separate particles. Just as the tides raised by the Moon tend to retard the motion of the Earth, so the Earth tides raised in the Moon have already done their work. The Moon now rotates on its axis in the same time as it revolves round the Earth. Part of the evolution of the Earth-Moon system is completed. Professor Schiaparelli's discovery that the rotation periods of both Venus and Mercury coincide with their times of revolution is distinctly confirmatory of Professor Darwin's theory.

"The general outcome of Professor Darwin's researches," writes Miss Clerke, "has been to leave Laplace's cosmogony untouched." All that he has proved is that the evolution of the Earth-Moon system has been unique in the Solar System, and cannot be regarded as typical of the development of other satellite systems. We may now briefly sum up the conclusions reached by Professor Darwin. First, we have a globe of molten matter now known as the Earth rotating in a very short period. As a result of this rapid rotation, or as a consequence of tidal friction, the globe ruptured in two, more probably taking the form at first of a mass of meteorites, and ultimately consolidating into a world. As a result of the tides, the Moon's rotation was retarded, and it was forced further

and further from the Earth, reaching at last its present condition. When the Moon revolves round the Earth in fifty-five days, and the Earth requires the same time to rotate on its axis, the solar tide will again interfere and the Moon will fall back on the Earth.

Professor Darwin impresses on his readers the view that, although his theory of the evolution of the Earth-Moon system has much in its favour, it cannot be regarded as proved beyond all doubt. He remarks, however, that it should have strong claims to acceptance. In his chapter on the "Evolution of Celestial Systems" in his book on "The Tides," he discusses the distribution of the satellites of the Solar System. He says of the evolution of a planet—"We have seen that rings should be shed from the central nucleus when the contraction of the nebula has induced a certain degree of augmentation of rotation. Now, if the rotation were retarded by some external cause, the genesis of a ring might be retarded or entirely prevented." He then remarks that probably the formation of the Moon was retarded, and in the case of Mercury and Venus, solar tidal friction prevented satellite formation. This explains why Mercury and Venus have no satellites, the Earth only one, and Mars two, while the exterior planets have each several satellites.

In 1897 Professor Darwin paid a visit to the United States, and delivered a course of lectures in the Lowell Institute at Boston. These were afterwards published in his book, "The Tides," already referred to, which appeared in 1898. A second edition was published in 1901. For his work regarding the tides, Professor Darwin received in 1892 the Gold Medal of the Royal Astronomical Society. On that occasion, the President said—"The Society is glad to welcome as its medallist one so worthy the name of Darwin as to have worked, where most men's energies would have flagged, at the theory of planetary evolution."

Apart from his studies of tidal friction, Professor Darwin has paid much attention to other branches of mathematics, and especially to figures of equilibrium of rotating masses of fluid.

In *Harper's Magazine* for December 1903, Professor Darwin gives a popular account of this interesting branch of research. He begins with imagining the existence in space of a mass of liquid such as water, rotating as if it were frozen. This sphere of liquid will gradually become flattened, and will typify a stable figure, similar to the various planets. As the speed of rotation increases, the mass becomes less stable, until finally it breaks up. Professor Darwin remarks, however, "if a series of figures be followed, and if it is found that at a certain stage of development there is a change from stability to instability, then we notice that there is another sort of figure coalescent with the first sort at the particular moment of change." Professor Darwin shows that the stability passes from planetary figures to ellipsoidal figures, and thence to pear-shaped figures. The results of various investigations, as Professor Darwin points out, indicate the tendency of a fluid planet to divide into two portions of unequal size. "It will probably," says Professor Darwin, "seem to some persons an extraordinary waste of time that a man should be willing to spend two years, as I have done, in endeavouring to determine a possible form of an ideal mass of liquid rotating in space. The field of research is apparently narrow, and the labour was great, yet it may be maintained that it is only in some such way as this that we shall ever be able to understand the processes of celestial evolution." Professor Darwin divides the formation of celestial bodies into two types. He classifies the origin of the planets and satellites as of the Laplacian type, and that of the Moon as of the second type.

Professor Darwin's services to astronomy have been recognised throughout the Scientific World. In 1885 he received the degree of LL.D from the University of Glasgow, and the Royal Society conferred on him one of their Royal Medals. He is a Fellow of the Royal Astronomical Society, and has served as President. He was in 1904 selected as President of the British Association for 1905.

Professor Darwin's studies of tidal friction have been the means of opening up a new branch in mathematical astronomy.

His striking researches have greatly extended our knowledge of the possible forms of celestial evolution. We may say with confidence that the remarkable discoveries which we owe to the distinguished mathematician form one of the most important recent contributions to speculative astronomy.

Edward Charles Pickering.

Edward Charles Pickering.

In observational astronomy remarkable progress has recently been made in the United States. It is there that the greatest number of discoveries are recorded. Photographic surveys of the sky, discoveries of new comets, studies of the surfaces of the planets, spectroscopic observations of the stars and nebulæ, which lead to many interesting discoveries—these are some of the fruits of the labours of the great American observers. Among them, Edward Charles Pickering occupies an exalted place.

Edward Charles Pickering was born in Boston, July 19, 1846. His father, Edward Pickering, was a grandson of Colonel Timothy Pickering, a Secretary of State under Washington. The future astronomer studied at Harvard College, Cambridge, Mass., where he graduated in 1865. In the same year he was, at the age of nineteen, appointed Instructor of Mathematics in the Lawrence Scientific School at Harvard. Two years later he became Thayer Professor of Physics at Massachusetts Institute of Technology, where he remained for nine years. In 1870 he invented a telephone receiver, which he publicly exhibited. Meanwhile he had become interested in astronomy, and was a member of the Nautical Almanac party, which observed the total solar eclipse of August 1869 The following year he became a member of the U.S. Coast Survey Expedition, which was sent to Spain for the purpose of observing the total eclipse of the Sun on December 22, 1870.

The American astronomer Winlock, the director of Harvard

College Observatory, died in 1875, and the position was offered to Professor Simon Newcomb, then employed at the Washington Observatory. Professor Newcomb, however, declined the position, which E. C. Pickering accepted in 1876. His first important work was in the field of stellar astronomy. In 1877 he began the study of photometry, or the determination of the exact brilliancy of the stars, a field of research then much neglected. It is a field of much importance, for it is only by studying the exact brilliancy of the stars that we may hope to discover their variations, their sizes, and their light-giving power. After he had tried various forms of instruments, Professor Pickering invented the "Meridian Photometer." The photometer was arranged so that the observer saw in the same field of view a reflected image of the Polar Star and a real image of some other star on the meridian. The effects of polarisation made the image of the star whose brilliancy was to be measured equal to that of the Pole Star, which is a standard star of the second magnitude. A prism then showed the difference of magnitude between the two stars. With the aid of the "Meridian Photometer" Professor Pickering succeeded in determining, in the years 1879 to 1882, the exact brilliance of 4,260 stars down to the sixth magnitude between the pole and thirty degrees of south declination. In the hope of determining the exact magnitudes of still fainter stars, Professor Pickering devised a still larger instrument of the same class, with which he made over one million observations on the brilliance of the stars. He also revised the magnitudes given in Argelander's great "Bonn Durchmusterung." Professor Pickering decided to extend the survey to the southern heavens. The meridian photometer was erected successively on three stations on the slope of the Andes, the third of these being Arequipa, where the Harvard auxiliary observatory is now located. The observations, conducted by Professor Bailey of Harvard, resulted in the determination of the magnitudes of nearly 8000 southern stars. The instrument was returned to Harvard, where the former photometric work was resumed, and was again sent to the new observatory at

Arequipa. For his work in stellar photometry, Professor Pickering received in 1886 the Gold Medal of the Royal Astronomical Society of London, along with the late Professor Pritchard of Oxford.

In the year 1880 Professor Pickering began searching the heavens for nebulæ by a new method, similar to that which Dr. Copeland employed some time later. The heavens were swept with a direct vision spectroscope, and points of light previously charted as stars were recognised by their gaseous spectra to be minute planetary nebulæ. The first sweep of the heavens was made on July 13, 1880, and an object which appeared to the eye as a minute star near λ Sagittarii proved to be a very small planetary nebula. Another object found on August 28 of the same year, near υ Sagittarii, proved to be a planetary nebula which had been observed as a star on three occasions, once by Argelander, and twice at the Washington Observatory. Other objects were also observed in the same year which proved to be minute planetaries. These nebulæ, which disclose to the eye nothing of their nebulous appearance, are either very small or extremely remote.

Professor Pickering, after his appointment at Harvard, devoted considerable attention to variable stars. In 1880 he proposed the division of variables into five classes. Class I. is represented by temporary stars, Class II. by stars undergoing large variations in long periods, such as *Mira* Ceti, and Class III. by irregular variables, similar to *Betelgeux*. Class IV. contains variable stars of short period, such as δ Cephei and β Lyræ, and Class V. the eclipsing stars, such as *Algol* and λ Tauri. In 1880 Professor Pickering made a mathematical investigation of the eclipsing-satellite theory of *Algol*, originally advanced by the English astronomer Goodricke in 1782. Professor Pickering came to the conclusion that if a bright and dark star revolved round their centre of gravity in 2 days 20 hours 48 minutes and 55 seconds, with an orbit nearly in the plane of our line of sight, the bright star would be partially eclipsed at each revolution and would appear as variable. He also suggested that spectroscopic observations by means of

Doppler's principle might throw some light on the subject. The "eclipsing-satellite" theory was fully confirmed by Dr. Vogel's spectroscopic observations in 1888 and 1889.

The next great work accomplished by Professor Pickering was in spectroscopic astronomy. This was in the form of a memorial to Professor Henry Draper, the successful astronomical photographer, who secured pictures of the Moon and stellar spectra. His early death in November 1882, at the age of forty-five, cut short his labours in stellar spectroscopy. Funds were, however, provided by his wife for the compilation of a catalogue of stellar spectra at the Harvard College Observatory under the direction of Professor Pickering. The catalogue, which was published in 1890, contains the results of a survey of the entire northern hemisphere and part of the southern, the telescope used being of 8 inches aperture. The spectra of 10,351 stars were investigated by Professor Pickering, and he subdivided Secchi's spectral types into various classes, designated by the capital letters of the alphabet. The Sirian type is divided into four classes, and the solar into eight, while the third and fourth types of Secchi each constitute a separate class.

The Draper Catalogue enabled Professor Pickering to investigate the very interesting question of the distribution of the spectral types. He divided the sky into forty-eight equal portions, and thus compared the numbers of different types which occurred in the different regions. He arrived at the conclusion that stars of the second and third types are distributed equally over the heavens. Things proved, however, very different in the case of the first type stars, which Professor Pickering found to be clustered near the Milky Way, which he believes to be "a distinct cluster of stars, to which, from its composition and age, the Sun does not seem to belong." This remarkable discovery, which was made independently by Sir David Gill at the Cape Observatory, and was indicated by the researches of Professor Kapteyn, is a considerable extension of our knowledge of the Universe, indicating some special law of spectral distribution.

Some very remarkable discoveries were made during the photography of the stellar spectra. One of these may be called the opening of a new era in sidereal astronomy. It was the direct confirmation of Bessel's idea about the "astronomy of the invisible." Professor Pickering photographed the spectrum of *Mizar*, the second star in the handle of the "Plough," in 1887, and again in 1889. On some of the photographs the line marked K was seen to be doubled, while on others it was seen under its usual aspect. The conclusion was then reached that *Mizar* belonged to a class of stellar bodies different from those already known. The doubling of the lines indicated that the star which we see as single is in reality composed of two bodies in revolution round their centre of gravity, in fact, belonging to a new type of double stars so close together that even the largest telescopes cannot divide them. The period of revolution was at first believed to be 104 days, but this has been since diminished by Professor Vogel to 20 days. Both the component stars of *Mizar* are of Seechi's first or Sirian type.

Another similar discovery was announced late in the same year. Photographs of the spectrum of the star β Aurigæ, near *Capella*, proved it to be also a spectroscopic binary, the components revolving round their centre of gravity in about four days. This discovery was actually made by Miss A. C. Maury, one of the lady assistants at the Observatory. The existence of this new type of double stars was confirmed at Potsdam by Professor Vogel's discovery of the duplicity of *Spica*, as we saw in our chapter on the great German astronomer. In 1896, also, Professor Pickering announced the duplicity of μ Scorpii and 3,105 Lacaille, detected on the Arequipa photographs. Still another star, β Lupi, was announced to be double in January 1898. The new branch of double-star astronomy has since been followed up with great success by Professor Vogel, Professor Campbell of the Lick Observatory, and Dr. Bélopolsky of Pulkowa.

Professor Pickering long contemplated the establishment in the southern hemisphere of an auxiliary station to the Harvard

Observatory. His brother, Mr. W. H. Pickering, now known as one of the leading astronomers of the United States, visited various localities in order to test the condition of the atmosphere, and in 1891, Arequipa, on the slope of the Andes in Peru, was fixed upon as the site of the new observatory. Under Professor Pickering's auspices a survey of stellar spectra in the southern hemisphere was undertaken. The Arequipa Observatory was endowed with a 14-inch photographic telescope, with which 75,000 photographs had been obtained to the beginning of 1901.

Professor Pickering has paid attention to stellar evolution, and concurs with Dr. Vogel in believing red stars of Secchi's third type to be suns on the road to extinction. He wrote in 1893:—"In general, it may be stated that, with a few exceptions, all the stars may be arranged in a sequence, beginning with planetary nebulæ, passing through the bright-line stars to the Orion stars, thence to the first type stars, and by insensible changes to the second and third type stars. The evidence that the same plan governs the constitution of all parts of the visible universe is thus conclusive."

Professor Pickering has paid much attention to charting the sky photographically. As a result, several new or temporary stars have been found on the Harvard plates. *Nova* Aurigæ, which was discovered by Dr. Anderson, of Edinburgh, in the end of January 1892, was found by Professor Pickering to be imprinted on plates taken at Harvard as early as December 10, 1891. The new stars which appeared in Perseus in 1887, in Norma in 1893, in Carina (Argo) in 1895, in Centaurus in 1895, in Sagittarius in 1898, and in Aquila in 1900, would almost certainly have escaped detection but for the Harvard photographs, on which they were found by Mrs. Fleming, one of the lady astronomers at Harvard. Professor Pickering studied *Nova* Persei in 1901, and observed its spectrum while the star was still increasing in brilliance.

Professor H. H. Turner of Oxford says of the detection of changes in the heavens:—"The energetic director of the Harvard Observatory has begun to accumulate material for

noting changes. He charts the sky once a month. . . . More than this, with a smaller instrument, and on a smaller scale still, he charts the brighter stars every fine night. So that if a star brighter than the sixth magnitude appeared in any quarter of the heavens he would have a record of it on the first fine night." As a result of Professor Pickering's plan of charting the heavens, the asteroid Eros, first seen visually at Berlin in 1898, was found to have been photographically discovered at Harvard in 1894; but, as the plates taken are far too numerous to be examined at once, the asteroid escaped detection. Professor Turner remarks very truly that "Professor Pickering and his assistants have done more than the whole astronomical world put together to indicate, and to carry out, schemes for the comprehensive and rapid survey of numbers of photographs."

Professor Pickering's contributions to astronomy have been so numerous and varied that we have been able only to notice the more striking among them. He has observed the planets with the photometer, and has estimated the sizes of the asteroids and of the satellites of Mars; he has discovered a number of variable stars, and has determined the nature of the light-curves of many others; he has also speculated on the possible cause of stellar variability. He considers it probable that the variable β Lyræ is a close binary, revolving in a circular orbit, with a radius of fifty million miles; he discovered in 1896, in the star ζ Puppis, a new series of hydrogen bands. In fact, his numerous works and investigations cannot all be described here. In 1901 he received a second Gold Medal from the Royal Astronomical Society. Professor Pickering is a member of most of the scientific societies both in Europe and in the United States. For his services to science he received the Draper Medal from the Washington Academy of Sciences, an honour which was also conferred on both Sir William Huggins and Dr. Vogel. Professor Pickering received the degree of S.B. from Harvard in 1865 and A.M. in 1880. The Universities of California and Michigan, in 1886 and 1887 respectively, conferred upon him the honorary degree of LL.D.

In the spring of 1902, in recognition of the fact that he had completed twenty-five years as director, the staff of the Harvard Observatory presented Professor Pickering with a silver cup.

During Professor Pickering's twenty-seven years of service at the Harvard College Observatory the number of his assistants has been increased from four to forty; and over thirty quarto volumes of "Harvard Annals" testify to the magnitude and importance of the work accomplished by Professor Pickering. As an example of his perseverance and energy, it may be said that, during a photometric study of *Algol*, he made on thirteen nights 2,748 comparisons with ω Persei, a neighbouring star, and of these six hundred were made in a single night, observation being continued for 8¾ hours. In a study of another variable, he made on five evenings 3,276 comparisons, and of these no fewer than nine hundred were made during a single night's observation!

The Harvard Observatory has recently purchased the most powerful reflecting telescope in existence, the famous five-foot reflector constructed by the late Dr. Common, the eminent English astronomer. In August 1904 Professor Pickering wrote—"It is hoped that in a few weeks the telescope may be received and mounted, and that observations to supply one of the great wants of astronomy, a measure of the light of the very faint stars can then begin. The work of many years has supplied this want for the brighter stars, and may now be extended to the faintest objects within the reach of human knowledge." We may therefore expect further discoveries and investigations from the illustrious astronomer of Harvard.

In closing this brief review of the life and work of Professor Pickering, we cannot do better than repeat the words of Mr. Knobel, who, as President of the Royal Astronomical Society, presented the Gold Medal to the great American astronomer in February 1901—"The study of the extensive researches and varied observations of our medallist reveals the lucid and vigorous mind that has been applied to the solution of so many difficult problems, and demonstrates the skill and energy which have enabled him to

obtain a complete mastery over the processes necessary for the accomplishment of his designs. . . . The history of the award of the Gold Medal is the history of men who have made an indelible mark in astronomy—whose labours have stimulated and pioneered others on the path of success, and whose disciples have expanded and developed the principles which they enunciated, to the realisation of such progress in astronomical science as we are witnessing at the commencement of the twentieth century. Among such a roll of distinguished men, Professor Pickering will surely take an honourable place as a brilliant leader, who, with rare skill, unwearied energy, and consummate ability, has known so well how to instigate, how to organise, and how to accomplish."

William Frederick Denning.

Much of our knowledge not only of planets, comets, and nebulæ, but perhaps the greater part of what we know of meteoric showers, is due to the unwearied labours of a self-made English astronomer, Mr. W. F. Denning, who has gained for himself a high position in the astronomical world. Mr. Denning has made the subject of meteoric astronomy peculiarly his own, and we may well repeat with Sir Robert Ball, "much of the recently-awakened interest in the subject has been due to the worthy example Mr. Denning has himself given us. Who among us would not be proud to imitate his single-hearted and enthusiastic devotion to the discovery of truth in this beautiful department of astronomy?"

William Frederick Denning was born on November 25, 1848, at the village of Redpost, near Radstock, in Somerset. His father was Isaac Poyntz Denning, of Bristol, while his grandfather fought in the Peninsular War. The future astronomer spent his childhood in Bristol, and at an early age became devoted to natural history. In 1865 he turned his attention to astronomy, and became in the following year the possessor of a 4½-inch refractor. In November 1866 he observed the great meteoric shower of that year, and was led to devote his attention chiefly to meteors, a branch of astronomy for which no telescope is necessary. In 1871 he became the possessor of a 10-inch silver-on-glass reflector, with which his observations on planets, comets and nebulæ have been conducted. In 1872 he communicated his first paper to the

William Frederick Denning.

(Photo. by J. Webb, Bristol.)

Royal Astronomical Society, on the great shower of Andromedid meteors on November 27, 1872. Between 6 and 6.30 that evening he enumerated from seventy-five to eighty meteors, and of these ten or fifteen were of the first magnitude. He determined accurately the position of the radiant point, about four degrees to the north of the star γ Andromedæ. In 1873 and 1874 he observed the Lyrids or April meteors and ascertained the place of the radiant. In 1876 Mr. Denning published his first list of meteoric radiants. This contained the determination, from his observations of the tracks of about nine hundred meteors, of the radiants of twenty-seven meteoric showers. In the following year he was elected a Fellow of the Royal Astronomical Society. He discovered in the same year that the great August shower of meteors exhibited a radiant point which, in consequence of the motion of the Earth, moved east-north-east at the rate of about one degree every day.

In the same year Mr. Denning made one of the most remarkable astronomical discoveries of modern times, that of so-called "stationary radiants." As is well known, the radiant point of a long enduring shower usually exhibits an apparent motion resulting from the combined orbital motions of the Earth and the meteors. But Mr. Denning found that, in some cases, the meteoric shower, although it lasted for months, persistently exhibited the same radiant point, implying that the motion of the Earth must be comparatively insignificant when compared with that of the meteors, which, the late Mr. Ranyard calculated, must be 880 miles a second. In 1884 Mr. Denning wrote: "The fact of stationary radiants exhibiting visible activity during several months is a phenomenon so unaccountable and so utterly opposed to the approved theories as to the orbits of shooting stars that it must receive a most crucial examination before it can be accepted." The difficulty of admitting so great a velocity led the late M. Tisserand to doubt the existence of stationary radiants; but astronomers generally agree with the words of Mr. Denning: "a well-attested fact of observation, however hard to reconcile

with known theories, ought on no account to be disregarded because of its non-conformity."

On October 3, 1881, Mr. Denning discovered a comet, which proved to be periodic, revolving round the Sun in over eight years. He also discovered comets on July 23, 1890, March 30, 1891, March 18, 1892, and March 26, 1894. The latter comet also proved to be periodic, revolving in a little over seven years. During his searches after comets Mr. Denning discovered about twenty new nebulæ, mostly in the north polar regions of the heavens.

In November 1882 Mr. Denning attentively observed Mercury with his 10-inch reflector. On the planet's surface he observed some dark irregular spots as well as a small brilliant spot and a large white area. Mr. Denning confirmed the blunted appearance of the southern horn of the planet, observed by Schröter in 1800. To Mr. Denning, rotation in a period of twenty-five hours was indicated. He concluded that "the markings on Mercury are far more decided and easily discernible than those on Venus; and that the aspect of the former planet presents a close appearance to the physical appearance of Mars." In a letter to Mr. Denning some time later, Professor Schiaparelli said—"You were right in saying that this planet is much easier to observe than Venus, and that his aspect resembles Mars more than any other of the planets of the Solar System." It is in the observation of Jupiter, however, that Mr. Denning has won his laurels as a planetary observer. He commenced to survey the planet at the time of the appearance of the great red spot, which he has studied since 1880, and, in his own words, has "investigated its early history and that of the objects around it." From 1898 to 1903 he determined on 4,195 occasions the time of transits of the principal objects on the surface of the planet, and from these he deduced the rotation periods of no fewer than 284 spots. The mean rotation period of Jupiter, as determined by the eminent English astronomer, from the great red spot, is 9 hours, 55 minutes, 36·56 seconds.

Mr. Denning's planetary observations, however, have been

merely incidental in a career devoted to meteoric observation. His enthusiasm has overcome all difficulties, and he has been rewarded by many discoveries. In July 1878 he discovered a rich shower of meteors from Aquarius, and on August 21-25 of the following year he recognised a shower from Draco. He also observed the great shower of Andromedids in November 1885, while he has devoted much attention to a shower the radiant of which is situated between α and η Aquarii. It was noticed that the orbit of Halley's comet approaches the orbit of the Earth, near the position occupied by the latter on May 4, and meteors accompanying the comet would exhibit a radiant near η Aquarii. However, the radiant-points did not quite coincide, and it remained for Mr. Denning to settle the question. In April and May 1886 he observed the meteors for twenty-seven hours and determined the radiant-point with great accuracy; "all doubt," says Sir Robert Ball, "of its agreement in place and date with the time and radiant-point of a shower connected closely in some way with the orbit of Halley's comet being thus clearly shown to be unfounded."

In 1890 Mr. Denning published in the *Monthly Notices* of the Royal Astronomical Society a list of 918 radiant points, deduced from his observations, between 1873 and 1889, of 9,177 meteors. In 1899 he published in the *Memoirs* of the Royal Astronomical Society a general catalogue of meteoric radiants, containing no fewer than 4,367 radiant points. In the thirty-one years, extending from 1872 to 1903, he determined the radiant points of 1,179 meteoric showers. Mr. Denning has devoted much attention to fireballs or "sporadic" meteors, and during the seventeen years from 1886 to 1903 he computed the actual paths of 370 of these wonderful objects. In a remarkable paper communicated to the Royal Astronomical Society in June 1894, he showed that the radiant points of these "sporadic" meteors are generally situated in the western part of the sky, while those of the meteoric showers are in the east. Occasionally, Mr. Denning has been able to trace some connection between fireballs and weak showers, but he concludes that they "must

either be merely single sporadic bodies, or else the survivors of some meteor group, nearly exhausted by the waste of its material during many past ages."

In 1890 Mr. Denning published his admirable book on "Telescopic Work for Starlight Evenings," which was followed in 1897 by a most interesting pamphlet on "The Great Meteoric Shower of November." In this work he devotes attention to the streaks or afterglows of these Leonid meteors. Mr. Denning points out that in some cases the streaks perceptibly increase in brightness after the meteors themselves have disappeared. "The fact that the streaks are often broken and visible in sections along the track, while they are always most intense at those particular parts corresponding with the greatest outbursts of light in the nuclei, strongly suggests that they are formed by exuded gas from the latter." He also says: "The streak-giving power of a Leonid, Perseid, or Orionid meteor is generally in proportion to its brilliancy."

In 1903 Mr. Denning made many important observations, both meteoric and planetary. The spots on Saturn were observed by him in the latter half of the year, and he determined the rotation period of the planet at 10 hours, 37 minutes, 56·4 seconds. In the *Monthly Notices* of the Royal Astronomical Society for June 1903, and in the great German periodical, the *Astronomische Nachrichten*, Mr. Denning described his observations on Mars, made at the opposition of the planet in the spring of 1903. He recognised many of the Martian canals, and observed the white cloud on the Martian surface, which was also seen by Mr. Lowell. Mr. Denning does not agree with the views put forward that the canals are illusory. He says: "There is really no doubt whatever about the streaked or striated configuration of the northern hemisphere of Mars." He regards the proximity of the double canals as accidental, and he adds regarding the markings on the Martian surface: "Their aspect is far more highly suggestive of natural than artificial production." From observations in the thirty-four years from 1869 to 1903, Mr. Denning determined the exact period of rotation of Mars as 24 hours, 37 minutes, 22·7 seconds. The display of

meteors on the morning of November 16, 1903, was observed by Mr. Denning at Bristol. He described it as about five times as rich as an average display of the Perseids. He finds, however, that the shower observed in America in 1901 was more plentiful than that watched by him at Bristol, when the meteors fell at the rate of about four per minute, as compared with six or seven per minute in 1901. He also observed the meteors of November 1904.

For his researches in meteoric astronomy, Mr. Denning received in 1895 the Valz Prize from the French Academy, and in 1898 the Gold Medal of the Royal Astronomical Society, on which occasion the address was delivered by Sir Robert Ball, then the President of the Society. For some years, Mr. Denning filled the office of President of the Liverpool Astronomical Society. To the *Monthly Notices* he has contributed ninety papers. In addition to journalistic work, he pursues the profession of accountant in Bristol, but nevertheless, he is an indefatigable worker, and has done more for the observation of meteors than any other living astronomer. In the autumn of 1904, he was granted in reward for his services to science a pension of £150 a year.

Mr. Denning's researches on meteors have been entirely non-telescopic, and show how much may be done for astronomy by observation with the naked eye. In 1890 he wrote as follows on his meteoric observations: "My plan of working may be briefly described as follows:—All the observations were made in the open air and from the garden adjoining the house. Attention was almost invariably given to the eastern sky. In mild weather I sat in a chair with the back inclined at a suitable angle; but on cold, frosty nights, I found it expedient to maintain a standing posture, and sometimes to pace to and fro, always, however, keeping the eyes directed towards the firmament in quest of meteors." He uses a perfectly straight wand as a help and corrective to the eye in ascribing the lines of flight. "When a meteor was seen, the wand was immediately projected upon its track and the position quickly noted and reproduced on an 18-inch celestial globe."

It will thus be seen that Mr. Denning's meteoric researches have been entirely conducted with the naked eye. He arrived upon the scene at a peculiarly appropriate time, when the investigations of Signor Schiaparelli had demonstrated the cometary nature of meteors, and had shown that these meteor streams were worthy of careful study. By his unwearied efforts, Mr. Denning has greatly increased our knowledge of meteors, and has gained for himself a unique position among modern astronomers.

Hugo Seeliger.

(Photo. by Baumann, Munich.)

Hugo Seeliger.

THE subject of our present chapter occupies an eminent position among modern German astronomers. His researches, not only on the construction of the heavens and the distribution of the stars, but also on temporary stars and other astronomical subjects, have gained for him an enduring reputation. To Professor Hugo Seeliger we are indebted for many remarkable observations and theories, which have done much for the advancement of astronomy.

Hugo Seeliger was born at Bielitz-Biala, in Silesia, on September 23, 1849. He received his early education in the Gymnasium at Teschen, and in 1867 entered the University of Heidelberg, where he studied for a year under such distinguished scientists as Kirchoff, Helmholtz, and Bunsen. In 1868 he entered the University of Leipzig, studying astronomy under Bruhns, and mathematics under Neumann. In December 1871 he graduated Doctor of Philosophy, his dissertation being devoted to the movements of double stars. Soon after this he was appointed volunteer assistant in the Leipzig Observatory, and in 1873 was called to the Bonn Observatory as assistant to Argelander. At Bonn he commenced his important work in practical astronomy. With the Meridian Circle he determined the positions of 20,000 stars in the zone, extending from forty to fifty degrees of north declination, for the catalogue of the Astronomische Gesellschaft. In 1874 Dr. Seeliger led an expedition which observed the transit of Venus from the Auckland Islands, and he returned to Bonn

in July 1875. He retained his position at Bonn for six years. becoming in 1877 "Privat-Docent" for astronomy in the University.

In 1881 Dr. Seeliger was promoted to the position of director of the Gotha Observatory, but he retained this position for only one year. In 1882 he was called to Munich as director of the Royal Observatory and Professor of Astronomy in the University. The observations of one of his predecessors at Munich, the Scottish astronomer Lamont, were reduced by Dr. Seeliger into a catalogue of 30,082 stars. During the four years from 1884 to 1888 Professor Seeliger's assistant, Dr. Bauschinger, determined with the Meridian Circle the positions of 13,200 stars from the seventh to the tenth magnitude. These determinations were published in the second Munich Catalogue, which contains stars situated within about twenty-five degrees both north and south of the equator. On the publication of the catalogue it was remarked that Professor Seeliger is "doing good work at the Observatory, both in the series of observations which are being carried out there, and also in the prompt publication of the results, so as to render them available to astronomers generally."

In 1888 Professor Seeliger confirmed the theory — first suggested by the younger Cassini and Thomas Wright, and mathematically demonstrated by Clerk-Maxwell in 1857—of the meteoric constitution of Saturn's rings. He pointed out, as the result of photometric observations, that the changeless lustre of the outer rings under all angles of illumination clearly proves that they are composed of small bodies. Professor Seeliger also showed that the dusky ring, being formed of bodies more thinly strewn, reflects less light. The fact that the dusky ring appears dark against the body of the planet is explained by Professor Seeliger, who considers the darkening to be due to the numerous shadows of the small bodies transiting the planet's globe. The theory was spectroscopically proved in 1895 by the late Professor Keeler, and his results were confirmed by Dr. Campbell, Dr. Bélopolsky, and M. Deslandres.

Professor Seeliger's remarkable researches on the double star ζ Cancri—the first application to the stars of the problem of three bodies—were published in 1889. This remarkable star was first seen as double by Tobias Mayer in 1756; and twenty-five years later Herschel found the larger star to be itself double. Before the close of 1840 the period of revolution was proved to be sixty years. The third star of the system apparently moves round the close pair in about six or seven hundred years. In 1873 M. Flammarion discovered that this movement is very irregular. To use the words of Miss Clerke: "The path traced out in the sky, far from being a smooth curve, is looped into a series of epicycles, in traversing which the star alternately quickens and slackens, or even altogether desists from its advance, while increasing or diminishing, by proportionate amounts, its distance from the centre of motion." Professor Seeliger took up the subject, and put forward an explanation which has met with almost universal acceptance. He showed that the third star revolves round a dark body in about 17½ years, and that Herschel's close pair, mutually revolving in sixty years, also moves round the dark body, which appears to be the most massive in the system. This remarkable group of stars, which Professor Seeliger's mathematical researches disclosed, appears to be modelled on the Ptolemaic design. "A cool, dark globe," Miss Clerke says, "clothed possibly with the vegetation appropriate to those strange climes, and plentifully stocked, it may be with living things, is waited on for the supply of their needs by three vagrant suns, the motions of which it controls, while maintaining the dignity of its own comparative rest."

After the appearance of the new star in Auriga in 1892, Professor Seeliger put forward his general theory of temporary stars, which, says Professor Frost, "certainly affords a better explanation of many of the phenomena observed than any other hypothesis yet suggested." Professor Seeliger's theory is that temporary stars are caused by the movement of a dark star through nebulous matter, which, as the photographic researches of Professor Barnard and Professor Max Wolf have

shown, is extensively diffused throughout space. A dark body, on entering the nebula, will be reduced to incandescence, just as a meteor is vaporised in the Earth's atmosphere. The result is the production of two spectra, that given out by the incandescent body being continuous and crossed by dark bands, while the spectrum emitted by the nebula consists of bright lines. Professor Seeliger considers that, in the case of *Nova* Aurigæ, the star passed through the nebula in three months, and that during its passage its brightness and spectroscopic appearance underwent considerable variations. The revival of *Nova* Aurigæ in August 1892 is also explained by the theory. Possibly the region which the star passed through was one in which nebulæ were thickly clustered, or probably the second conflagration was caused by the star entering an adjoining portion of the nebula.

In some respects, Professor Seeliger's theory of temporary stars is the most probable yet propounded; but it is still impossible to decide which of the three theories, advanced respectively by Sir William Huggins, Professor Vogel, and Professor Seeliger, is correct. One point, however, is plain. It is much more probable that a dark star should enter a diffused mass of nebulous matter, as Professor Seeliger's hypothesis requires, than that a collision or very close approach between two stars should actually occur, as is indicated by the other theories.

As early as 1884 Professor Seeliger commenced his researches on the distribution of the stars, which were made public in a series of papers presented to the Munich Academy during the fourteen years from 1884 to 1898. These researches are called by Professor Newcomb "the most thorough study of the distribution of the great mass of stars relative to the galactic plane." Professor Seeliger's researches were based on the *Durchmusterung* of Argelander and Schönfeld, on the star-gauges of the Herschels, and on Professor Celoria's count of stars, which was mentioned in our chapter on that astronomer. Professor Seeliger divides the sky into nine zones, each twenty degrees in breadth, by small circles parallel to that of the

Milky Way. Thus his first zone or "region" includes the north galactic pole, his fifth "region" contains the great circle which forms the central line of the Milky Way, while the south galactic pole is included in the ninth. In Professor Seeliger's first region is included 4,277 stars, in the second, third, and fourth respectively 10,185, 19,488, and 24,492 stars. The maximum is reached in the fifth region, which contains 33,267 stars, and it is to be noted that this is the galactic zone. The sixth region contains 23,580 stars, and the seventh, eighth, and ninth respectively 11,790, 6,375, and 1,644 stars. The number of stars gradually increases from each of the galactic poles to the Milky Way itself. It is obvious that if the Galaxy were simply a ring of stars surrounding a star-sphere the number of stars would increase not steadily, but suddenly near the bound ary of the ring. The conclusion which may be drawn from these researches is that the Universe is flattened at the galactic poles, the number of stars constantly increasing towards the Galaxy itself. In Professor Seeliger's own words: "The Milky Way is no mere local phenomenon, but is closely connected with the entire constitution of our stellar system."

Following up these researches, Dr. Seeliger estimates that the distance between our Solar System and the inner border of the "zone of stellar condensation," that is, the actual Milky Way, is 500 times the distance of *Sirius*, and the external border 1,100 times that distance. This places the limits of the Universe at a distance of about 9,000 light-years from the Solar System. According to Dr. Seeliger, the Stellar Universe is finite in extent. In his opinion, there is no extinction of light in the Galaxy, but across the vast space which separates *our* Universe from other and external Galaxies, extinction probably comes into play and cuts off the feeble rays of external Universes. Professor Seeliger's views agree with those of Mr. Gore. The researches of Dr. Seeliger are a distinct advance on previous investigations on the construction of the heavens. He tells us, approximately, the extent and shape of the Universe, and his results are established on a firm basis. He has approached the great problem with enthusiasm

and perseverance, and his results take us much nearer to its solution.

In this sketch, we have only been able to indicate Professor Seeliger's most important researches. We must pass over, with a mere mention, his extensive studies of Astro-photometry, of the theory of probabilities, and the theory of errors of observation. He has exhaustively studied, also, the enlargement of the Earth's shadow during lunar eclipses, the perturbation theory, the origin of comets, the theory of astronomical instruments, and the application of the law of gravitation. As he remarked in a letter to the writer, he believes to "have shown that the Newtonian law is not in every case of strict application." In 1892 Professor Seeliger was elected an Associate of the Royal Astronomical Society, and since 1896 he has been President of the Astronomische Gesellschaft. His scientific papers are to be found in the *Astronomische Nachrichten* and the Proceedings of the Munich Academy.

Professor Seeliger's remarkable researches have been distinguished by much study, care, and enthusiasm. He is primarily a practical astronomer. To that branch of the science he has rendered important services, while his careful discussions of the distribution of the stars, his mathematical investigations, and his speculations on temporary stars place him among the most distinguished modern astronomers. His astronomical labours are a brilliant example of careful observation, patient study, and profound thought.

Jacobus Cornelius Kapteyn.

(Photo. by A. S. Weinberg, Groningen.)

Jacobus Cornelius Kapteyn.

NOTWITHSTANDING the great progress made in our knowledge of the heavens by the astronomers of the present day, comparatively few of them have devoted their attention exclusively to the great problem of the construction of the heavens. Former investigators in this branch of research had only telescopic material to work upon; but the discoveries of the great spectroscopic astronomers have resulted in an enormous increase in the material on which to base an investigation of the construction of the Universe. Such an investigation has been undertaken by the distinguished Dutch astronomer whose life-work forms the subject of this chapter.

Jacobus Cornelius Kapteyn was born at Barneveld, in Gelderland, January 19, 1851. In 1869 he entered the University of Utrecht, where he studied for six years. During his University career, his attention was drawn towards mathematics and astronomy, and while still a student he applied for the vacant post of assistant in the Leyden Observatory and received the appointment. As he remarked in a letter to the writer, had a place of assistant of physics been vacant, his scientific career would probably have been altogether different. At Leyden his astronomical interest was sustained, the refined method of observation having a particular charm for him. In the end of 1877 Dr. Kapteyn was appointed Professor of Astronomy in the University of Groningen, where, early in 1878, he began his lectures with an address on the parallaxes of the stars. The chair at Groningen

being a new one, Professor Kapteyn expected that the Dutch Government would order the erection of an observatory attached to the University; but the years passed on, and still there was no sign of its foundation. Accordingly, as Professor Kapteyn could do nothing for observational astronomy, he turned his attention to pure mathematics, and published some important mathematical papers in 1883, 1885 and 1886.

In 1884 Professor Kapteyn obtained permission from Professor Bakhuyzen * of Leyden to use the meridian circle of the Leyden Observatory for an investigation of stellar parallax. Professor Kapteyn began his observations in 1885. The observations were divided into four periods, namely, March 29 to April 23, 1885; November 20, 1885 to January 16, 1886; November 26, 1886 to January 9, 1887; and March 27 to May 1, 1887. After an elaborate choice of comparison stars and methods for the elimination of errors, the observations were made, and the results were published in Professor Kapteyn's "Bestimmung von Parallaxen durch Registrir Beobachtungen am Meridiankreise," which appeared at the Hague in 1891. During his two years' observations Dr. Kapteyn determined by meridian observations of the differences of right ascension, the parallaxes of fifteen faint stars, θ Ursæ Majoris, 20 Leonis Minoris, the stars numbered 18115, 19022, 20670, 21185, and 21258 in Lalande's Catalogue; 1618, 1646, 1812, 1822, 1830, and 1855 in Groombridge's Catalogue; and X 96 and XI 218 in the catalogue of Piazzi. Of these Lalande 21185 proved to have comparatively a large parallax, indicating its proximity to the Solar System.

While occupied in his work on the stellar parallax, Professor Kapteyn heard of Sir David (then Dr.) Gill's proposal to extend the *Durchmusterung* of Argelander and Schönfeld to the southern heavens. Professor Kapteyn accordingly pro-

* E. F. van de Sande Bakhuyzen, Professor at Leyden, succeeded the late Professor Kaiser. He determined in 1884 the rotation period of Mars with great precision, and in 1892 made an elaborate determination of the motion of the Solar System.

posed that Sir David Gill should leave to him the work of measuring the photographs of the heavens and reducing them to the form of a catalogue. Professor Kapteyn was occupied with this work for fourteen years, until in 1900 the great catalogue, known as the *Cape Photographic Durchmusterung*, was completed. "It is to my colleague and friend whose name appears on the title page," wrote Sir David Gill, "to whom I am under the deepest obligation. At a time of great stress and discouragement, he lifted from my shoulders a load of responsibility by his noble and spontaneous offer to undertake the measurement of the plates, the computation of the results, and the formation of the catalogue. . . . . I feel assured that Kapteyn has not laboured in vain, and that astronomers will duly appreciate what he has done for their science."

The following tribute to the skill and patience of the Dutch astronomer is from the pen of Professor Newcomb:—"This work of Kapteyn offers a remarkable example of the spirit which animates the born investigator of the heavens. Although the work was officially that of the British Government, the years of toil devoted to it were, as the writer understands, expended without other compensation than the consciousness of making a noble contribution to knowledge, and the appreciation of his fellow-astronomers of this and future generations."

While Dr. Kapteyn was occupied in reducing and measuring the photographic plates, one of the Professors at Groningen lent him two rooms in the physiological laboratory, where the measurement and reduction of the plates—in fact, almost the whole work of the *Durchmusterung*—was accomplished. In 1896 a large part of the dwelling previously occupied by the Governor of the province of Groningen was lent to Professor Kapteyn, who converted it into an astronomical laboratory, a place where photographs are measured and reduced, and investigations undertaken regarding the distribution of the stars. The laboratory, which was opened on 16th January, 1896, has now been removed to the former mineralogical

laboratory, where it has got a permanent position. Ably assisted by Mr. De Sitter, Professor Kapteyn has there accomplished much valuable work.

Dr. Kapteyn's name is imperishably associated with the problem of the construction of the heavens. While employed measuring and reducing the plates for the *Cape Durchmusterung* his attention was drawn to the great question. In 1891 he noticed that both first and second type stars are bluer and more easily photographed in the Galaxy than elsewhere. This, however, was merely the beginning of his investigations. On April 29, 1892, he read before the Amsterdam Academy of Sciences a preliminary paper on the distribution of the stars. This was followed by another paper on 28th January, 1893. His researches related to 2,357 stars—1,189 of which were classed in Professor Pickering's catalogue of stellar spectra as of the first type, 1,106 of the second, and 62 of the third. By an ingenious method, Professor Kapteyn succeeded in studying the distances of the stars without measuring their parallaxes. As is well known, as a result of the motion through space of the Solar System, there is an apparent motion of the stars, and the nearer a star is to the Solar System, the greater is this apparent motion; the stars, however, are also moving. Astronomers therefore resolve the proper motions of the stars into two components, that dependent on the solar motion being known as the parallactic motion, as it is relative to the star's parallax or distance. Professor Kapteyn, in order to reach a definite idea of the average distances of the stars, made use of another measure, the component of the proper motion measured at right angles to a great circle of the sphere which passes through a given star and the apex of the solar motion.

Professor Kapteyn discovered that on the average, stars of the first type have smaller proper motions than those of the second type. Either, therefore, stars of the second type move more swiftly than stars of the first, or the average rate of motion is the same for both types, only the stars of the second type are nearer to the Solar System than those of the first. Professor Kapteyn concludes in favour of the latter view. He

is of opinion that "the near vicinity of the Sun contains nearly exclusively stars of the second type; with increasing distance the proportion of the number of stars of the first type to that of the second grows gradually." That the second-type stars are, on the average, nearer to the Sun than the first-type stars of equal brilliance, is, in Professor Kapteyn's view, incontrovertible. It is not a theory founded on the greater proper motion alone of the second-type stars, but is demonstrated by their greater parallactic motion.

In 1893, Professor Kapteyn concluded that the vicinity of the Sun contained almost exclusively stars of the second type, in fact, that the groups of second-type stars formed one system, which was termed "the solar cluster." He considered its shape to be roughly spherical, and likened it to the Andromeda nebula. The point of maximum condensation was believed to lie in the constellation Andromeda, supposed by some to represent the central point of the Galaxy. In his paper "On the Luminosity of the Fixed Stars," which appeared in 1902, Professor Kapteyn abandoned the idea of a solar cluster, finding the theory to be very probably erroneous. This, however, is only a small portion of his work. The other points established by him are fully confirmed.

The motion of the Solar System has long been a favourite subject with Professor Kapteyn. In 1900 he made an elaborate investigation, determining the position of the solar apex. The paper of 1900 was followed by others in 1901 and 1902. Professor Kapteyn finds a position of the solar apex nearly similar to that found by Professor Newcomb and Professor Campbell. In the paper of 1901 he remarked that a solar velocity of eleven miles a second is "the most probable value that can at present be adopted." This result is confirmed by spectroscopic observations by means of Doppler's principle.

In 1889 it was proposed by Professor Kapteyn that each plate for the astrographic catalogue should be exposed at three epochs of maximum parallactic displacement. He also suggested that they should be carefully preserved during the six months and then developed. They would then furnish a

determination of the parallaxes of the stars. The proposal of the Dutch astronomer was not adopted; but in 1891 photographs for stellar parallax were exposed at Helsingfors Observatory, and Professor Kapteyn, from measures of these plates, made approximate determinations of the parallaxes of 248 stars; but he considers these investigations as merely an experiment. He has, however, prepared a table of probable parallaxes of stars of the first and second types down to the eleventh magnitude.

During his examination of the plates for the *Cape Durchmusterung*, Professor Kapteyn, in 1897, was struck with the appearance, on one of the plates, of a star which could not be found in any catalogue. On consulting other photographs and lists of stars, he found that the star had been seen before, but always in different positions, proving its possession of an exceptionally rapid proper motion, greater than that of any other known star. It is of the eighth magnitude, and situated in the southern constellation Pictor. Professor Kapteyn paid considerable attention to the new star which appeared in Perseus in 1901. It will be remembered that photographs taken in September 1901 in America revealed the existence, surrounding the new star, of a spiral nebula moving with an almost incredible velocity. Professor Kapteyn rejected the idea that the nebulous matter was actually moving. He came to the conclusion that the nebula was seen only by the reflected light of the new star, and, in Miss Clerke's words: "Its various spires and condensations have come successively into view as the flare of the explosion travelled outward in widening circles." This theory was supported by Professor Seeliger.

In 1892 Professor Kapteyn was elected an Associate of the Royal Astronomical Society. In February 1902 he received the Gold Medal. On that occasion, the President, Dr. J. W. L. Glaisher, made the following tribute to the work of the great Dutch astronomer: "One spirit runs through all Kapteyn's work, namely, an effort to treat the great cosmical problems comprehensively. . . . . Always occupied with the most

effective means of attacking the great problems of the Universe, he has never flinched from the heavy labour required to carry his ideas into practice; and it is very fitting that one whose mind has been from the first so much attracted by the more difficult questions presented by the statistics of the heavens should himself have contributed such invaluable material for the study of the subject which he has so much at heart."

The elaborate researches of Professor Kapteyn have resulted in a great extension of our knowledge of the parallaxes and proper motions of the stars, of stellar distribution and the construction of the heavens. He has been enabled, thanks to his unconquerable perseverance and energy, to establish several important truths regarding the distances and motions of the stars—truths which have done much to open the way for investigations on the actual elements of our Universe, and which shall testify to all time of the brilliant and wonderful researches of this illustrious Dutchman.

The scientific career of Professor Kapteyn is an example of perseverance under difficulties. Without an observatory he founded an astronomical laboratory; simply because he had no opportunities for observing he undertook the reduction of the Cape photographic plates; and this has led to his studies of proper motion and parallax, in which branch of research he has been a pioneer. Professor Kapteyn has not only gained for himself a lasting place in the history of astronomy, but he has reflected lustre on his native country.

Edward Walter Maunder.

AMONG the English astronomers who have extended our knowledge of the Sun and stars by means of the spectroscope, a high place must be given to Mr. E. W. Maunder, senior assistant in the Royal Observatory, Greenwich, and superintendent of the Solar department of that institution. Mr. Maunder's chief services to astronomy have been his observations of the Sun, and his spectroscopic observations of the stars, in which branch of the science he is one of the highest authorities.

Edward Walter Maunder, the son of a Wesleyan minister, was born in London on April 12, 1851. He was educated at University College School and King's College, London, where he successfully pursued studies in science. In 1873, at the age of twenty-two, he entered the Royal Observatory, Greenwich, as an assistant astronomer, and was two years later elected a Fellow of the Royal Astronomical Society. The work assigned to him at Greenwich was to photograph the Sun daily, and to measure and reduce the photographs; while he also made visual observations of the solar spots and prominences, as well as comets and stars. As early as 1877 Mr. Maunder, with the 12¾ Merz refractor of the Greenwich Observatory, made a thorough study of Mars, at the time of the famous opposition of that year, when Professor Schiaparelli discovered the canals. From some of these drawings, made from 1877 to 1882, Mr. Maunder considers "it will be seen that I had recorded some of the markings now familar to us as 'canals' and 'oases'

Edward Walter Maunder.

(Photo. by Elliot & Fry, London.)

even before Schiaparelli had published his results, and quite a number before they had been generally recognised by observers."

Soon after his appointment at Greenwich, Mr. Maunder commenced his spectroscopic studies. Along with Mr. Christie—now Astronomer-Royal—Mr. Maunder began in 1875 an important series of observations on their radial motions with the 12¾-inch Merz telescope at Greenwich. In Mr. Maunder's words: "The telescope was not powerful enough to do much more than afford a general indication of the direction in which the principal stars were moving," and to confirm the investigations of astronomers on the solar motion. This work of Mr. Maunder, with the exception of the earlier observations of Dr. Vogel, was the first on the radial motions of the stars since the new kind of measurement was inaugurated by Sir William Huggins in 1868. Some valuable results were obtained at Greenwich, but they were by no means so accurate as those afterwards obtained at Potsdam, by means of photography. Considering, however, the great difficulty of such observations with the eye, they were remarkably accurate, and a distinct advance in our knowledge of the radial motions of the stars. Mr. Maunder's observations on the spectra of the planets deserve some notice. He specially observed Mars, and found the spectrum of the south polar cap specially bright towards the yellow end. He also observed lines of aqueous vapour in the spectrum of Mars; while he investigated the various lines in the spectra of Uranus and Neptune. Of special interest also, are Mr. Maunder's observations on the spectra of comets. Much attention was given to the comet of 1881 by both Mr. Christie and Mr. Maunder, and bright bands were discerned in its spectrum; Mr. Maunder perceived the spectrum of Comet Wells (1882) to be continuous on April 22 and May 11, and no bright lines could be discerned. On May 31, however, he noted the development of a bright line in the yellow portion of the spectrum, apparently coincident with the lines of sodium. On June 8 the line had become so brilliant that the continuous spectrum was almost obliterated

in comparison. He observed the comet telescopically, and noted it to be almost as red as Mars, showing that great disturbances had taken place. The comet passed perihelion on June 10, 1882, and was observed by Mr. Maunder in full daylight, when it appeared as a dull point of light.

Mr. Maunder's observations of the temporary star which appeared at the centre of the Andromeda nebula in 1885 are of especial interest. The spectrum, he remarked, was perfectly continuous, neither bright nor dark lines breaking its continuity. Some time later, when he again observed the new star, he suspected the presence of bright lines, but did not confirm the observation. The interpretation of Mr. Maunder's observations of the star is that it was not a temporary star in the same sense as were *Nova* Cygni, *Nova* Aurigæ, and *Nova* Persei. Some important observations on *Nova* Aurigæ were made by Mr. Maunder in 1892. He photographed the spectrum on February 22, 1892, and to use the words of Mr. Gore, his photograph "showed a displacement of the dark lines, which implied a relative motion of the two supposed colliding bodies of about 820 miles a second." Mr. Maunder concluded that the new star was the result of a collision.

Mr. Maunder, in 1890, founded the British Astronomical Association, and from 1894 until 1896 was its President. This society is of a less technical nature than the Royal Astronomical Society, and, in Mr. Maunder's words, "its chief purpose has been the association of observers for mutual help, and their organisation for the work of astronomical observation." To the *Journals* of the Association, Mr. Maunder is a frequent contributor. One of his first contributions dealt with his observations of the position of the "chief nebular line," which Professor Lockyer believed to coincide with the magnesium fluting. Mr. Maunder concluded that "we do not know the position of the nebular line with sufficient accuracy to say positively that it does or does not accord with the magnesium fluting." Later measures by the late Professor Keeler, however, showed that the line and the fluting did not coincide. Mr. Maunder's calculations as to the light-giving

power of various stars of the Solar and Sirian class are of great interest. He finds that *Procyon* and *Altair* have 25 times the light-giving power of the Sun, *Sirius* 40 times, *Aldebaran* 70 times, the Pole Star 190 times, *Capella* 220 times, and *Vega* and *Arcturus*, respectively, no less than 2,050 and 6,200 times the light-giving power of the head of our Solar System. All of these stars are much larger bodies than our Sun.

In 1891 Mr. Maunder was offered the position of spectroscopic astronomer at the Lick Observatory, in California, but he declined the offer, preferring to retain his post at Greenwich. Some time later he was invited to pay a six or nine months' visit to the observatory, with the assurance that the great 36-inch refractor would be placed at his disposal.

In solar astronomy, Mr. Maunder has earned a considerable reputation. In 1880 he noticed certain dark bands in the spectra of sun-spots which had not been previously observed. He has also given much attention to the solar periodicity, and has discussed the seventeenth-century observations of sun-spots. He has studied the Sun minutely, and perhaps his most important contrbution to solar astronomy has been on the connection of sun-spots and magnetic disturbance. In a paper contributed to the Royal Astronomical Society in January 1904, he remarks that there were nineteen great magnetic storms recorded at Greenwich in the twenty-nine years from January 1, 1875, to December 31, 1903. "All the nineteen took place without exception when there was present on the Sun a group of spots with projected area of over 1,000 millionths of the area of the visible disc; or when a group, at one time very large, had returned in a diminished form to the central meridian." Mr. Maunder finds, however, that every great sun-spot is not always answered by a great magnetic storm on the Earth. In his own words—"Every great spot on the Sun should be answered by a great magnetic storm here; every great magnetic storm should be synchronous with the appearance of some great spot; and further, the violence of the storm should bear a definite relation to the extent of the spot. This relation does indeed hold good if we

consider only the average of a number of instances; it does not hold good universally in every individual case." Mr. Maunder gave a plausible explanation of the discrepancy, arguing from the appearance of the solar corona. He considers that the coronal rays travel outwards from the Sun, the lines which compose the corona being "essentially lines of force." He believes the effect of a solar disturbance travels outwards in somewhat the same manner as the rays of the corona. "The intensity of any magnetic storm due to a solar disturbance would then depend upon two factors: first, the actual magnitude of the disturbance itself, and next, upon the distance of the Earth from the direction of maximum effect. We should find, as we actually do, that when the average was taken of a large number of cases, the frequency of magnetic storms and their intensity would correspond to the size of the solar spots."

During 1904 Mr. Maunder carefully pursued the subject and on November 11, read before the Royal Astronomical Society a paper which has been well said to establish "an entirely new conception of the solar action in producing our magnetic disturbances." After tabulating the important magnetic disturbances recorded at Greenwich from 1882 to 1903, he concluded that many disturbances recurred when the same solar meridian returned to the Sun's centre. Mr. Maunder pointed out that only one conclusion can be drawn from this discovery, that the cause of the magnetic disturbances is associated with limited areas on the Sun. To quote the admirable report of the meeting of the Society in *Knowledge and Scientific News*, "the magnetic action whatever its nature did not radiate equally in all directions, like light and heat, but acted along very definite and restricted lines. The mean rotation period indicated for these areas was the same as that given in the mean by the sun-spots; the extreme periods were those given by what we may fairly call the extreme sun-spots. Mr. Maunder found an analogy to these magnetic stream lines in the long rays of the corona, as photographed in the 1898 total solar eclipse. The solar action being of this nature, it is

perfectly clear that the stream lines from many spots may miss our Earth altogether, and hence a great spot need not necessarily be accompanied by a magnetic storm." Some of the disturbances, however, are repeated rotation after rotation when the associated spot has become invisible. This epoch-making paper demonstrates beyond a doubt the solar origin of magnetic disturbances.

Much of Mr. Maunder's work on the Sun, however, has been in connection with total solar eclipses. He has been on no fewer than five expeditions, and on most of these occasions he has been accompanied by Mrs. Maunder, who is also an accomplished astronomer. In 1886 Mr. Maunder observed the total eclipse of the Sun on August 29 of that year from the West Indies, where he secured a number of photographs of the corona. He also observed a great prominence "of the intensest silver whiteness" three hundred thousand miles in height. This observation confirmed those of Professor Tacchini. The expedition to Lapland, organised by the British Astronomical Association in 1896 was a failure, as the Sun was obscured by clouds; but in India, on January 22, 1898, Mr and Mrs. Maunder secured a valuable series of photographs. To observe the eclipse of 1900 Mr. and Mrs. Maunder, along with Mr. Maunder's two daughters—who also did some valuable eclipse work—visited Algiers and made a number of very valuable observations, the results being published in the volume on "The Total Solar Eclipse of May 1900" which was edited by Mr. Maunder. In May 1901 Mr. and Mrs. Maunder visited the island of Mauritius on another eclipse expedition, and again they were successful in their observations. In "The Indian Eclipse 1898" Mr. and Mrs. Maunder put forward the view that the solar prominences "represent centres of strong eruptive action and that in consequence of such action coronal matter is driven upward from the Sun over a very wide area in dome-like forms." In August 1900 Mr. Maunder pointed out that there is much diffused coronal light beyond the limits of the corona as generally observed.

Mr. Maunder has devoted considerable attention to the planet Mars and has propounded the only theory worthy of the name which can compete with Mr. Lowell's attempt to explain the markings on the red planet, which is dealt with in another chapter. He has opposed the view that the canals are artificial and wrote in 1895 after a careful study of the planet, in the *Journal* of the British Astronomical Association: "Canals, in the sense of being artificial productions, the markings on Mars which bear that name, certainly are not." A series of experiments, made by Mr. Maunder in 1902 and 1903 were described by him in *Knowledge* for November 1903, the object being to prove the reality or non-reality of the Martian canals. In conjunction with Mr. Evans, headmaster of the Royal Hospital School at Greenwich, Mr. Maunder arranged for a class of about twenty boys to copy at different distances three views of Mars, on which the canal system was not represented; as nearly all the boys drew canals on the copies, Mr. Maunder concludes that the canal system is largely an optical illusion, caused by the action of the eye in shaping minute details into regular forms. Mr. Maunder's theory, although accepted by some astronomers, has been hotly contested by others.

Mr. Maunder has devoted considerable attention to ancient astronomy, and especially to the antiquity of the constellations, a subject fully discussed by him in his "Astronomy Without a Telescope." In the first chapter of that volume, after a most interesting discussion, he concludes that "the ancient constellations were designed nearly five thousand years ago by a people dwelling somewhere between the Ægean and the Caspian, probably near the head of the valley of the Euphrates. . . . They had made some progress in astronomy, and were sufficiently organised for the work of constellation making to be carried out on a deliberate plan and to receive general acceptance."

In *The Observatory* for January 1904, Mr. Maunder published an interesting paper on the allusion to the Sun and Moon in the Book of Joshua. He attempts, by the description given, to locate the position of Joshua at the time. After a very

interesting discussion, Mr. Maunder concludes that the words uttered by Joshua prove that he was standing *at* Gibeon. The Sun was at the time within fifteen degrees of the zenith, and the time of the day was noon. Mr. Maunder also states that the date was about July 22 of the present calendar, and that the Sun must have risen exactly at 5 A.M. and set at 7 P.M. The Moon, he concludes, must have been about its third quarter and was within half-an-hour of its setting. Mr. Maunder was, however, unable to fix the year in which the words of Joshua are supposed to have been uttered.

Mr. Maunder is a member of several learned societies, including the Société Astronomique de France, and was Secretary of the Royal Astronomical Society from 1892 to 1897, was Vice-President some time later, and has served on the Council. In a sketch like the present it is impossible to mention in detail each of the investigations of this eminent English astronomer. Thus we must pass over, with a mere mention, his researches on the nature of nebulæ and on the Galaxy, and his ideas on the extent of the Stellar Universe. As an author on astronomy, Mr. Maunder has acquired a considerable reputation. In 1895 he succeeded the late Mr. A. C. Ranyard as Astronomical Editor of *Knowledge*, to which he has contributed a large number of papers. He has published two books on astronomy—"The Royal Observatory, Greenwich"—a valuable and instructive volume, which appeared in 1900—and "Astronomy without a Telescope" In the latter most interesting volume, publised in 1902, Mr. Maunder shows how much may yet be done in astronomy by means of the naked eye and the binocular; how the wonders of the Galaxy may be studied; how variable stars may be investigated; how temporary stars may be discovered; and how star colours may be observed, without the aid of a large telescope. At the close of his work is the following beautiful passage:—

"The fields of work which we have passed in review have been both many and varied. They have extended from phenomena the most slight and transient, the lighting of a

sunset cloud, the momentary flash of a meteor, to the greatest and most enduring that the Universe can show—the fabric of the Galaxy and its interweaving with the stars. And there is above all in this direct study of the heavens, out in the open, beneath the deep, unsounded sky, a charm and an awe not to be realised otherwise. It is nature at her vastest that we approach; we look up to her in her most exalted form. We see unrolled before us the volume which the finger of God has written; we stand in the dwelling-place of the Most High."

Aristarch Bélopolsky.

One of the greatest living spectroscopists, and one of the few astronomers, who, by means of the spectroscope, have discovered invisible stars and thus verified Bessel's prediction of the "astronomy of the invisible" is Dr. Bélopolsky, astrophysicist in the Pulkowa Observatory, near St Petersburg. By his various discoveries he has gained a permanent place in the history of astronomical science.

Aristarch Bélopolsky was born in Moscow on July 13, 1854. His parents were in humble circumstances, and he received his education for eight years in the Institute for Boys in that city. He then proceeded to the University of Moscow, where he studied for four years in the physico-mathematical faculty. On leaving the university he received in 1877 the position of assistant astronomer in the University Observatory of Moscow, which was directed by the late Professsor Brédikhine. At the Moscow Observatory M. Bélopolsky observed the Sun with the photoheliograph, and the planets, stars, and comets with the meridian circle. The results of those observations appeared in the Annals of the Moscow Observatory from 1878 to 1888. On August 19, 1887, M. Bélopolsky observed the total solar eclipse of that year from Jurjevitch on the Volga, and secured a valuable series of photographs.

In 1888 M. Bélopolsky was invited to the Pulkowa Observatory as assistant astronomer to M. Otto Struve, who was at that time director of the observatory. On the retirement of Dr. Struve in 1890, Professor Brédikhine received the appointment, and

he appointed M. Bélopolsky astrophysicist in the observatory. His first work at the observatory was the reduction, into the form of the Pulkowa fundamental star-catalogue, of the observations of Dr. Wagner, formerly chief assistant at the Observatory. While reducing these observations. M. Bélopolsky made in 1889 several determinations of stellar parallax. M. Bélopolsky also exhaustively studied the Sun. He showed in 1892 that faculæ do not conform to the laws of the solar rotation. In 1897 he demonstrated that changes in the solar corona correspond with surface disturbances. As a sun-spot minimum draws near, spots descend into lower latitudes, while the coronal cycle of changes is somewhat similar. According to M. Bélopolsky, the corona is rotating and in a much shorter period than the solar globe itself.

In 1892 M. Bélopolsky commenced his important studies in spectroscopic astronomy, which have been conducted with the 15-inch and 30-inch telescopes of the Observatory, and with a photographic glass. His first observations were on the new star which suddenly appeared in Auriga, in the end of 1891. His results were published in his paper, *Ueber die Nova Aurigæ* in the *Astronomische Nachrichten.* He made an exhaustive series of observations on the new star, and secured photographs with exposures of five hours. He also perceived one of the bright lines to be double at a time when the star was increasing in brilliance. In 1893 Dr. Bélopolsky called attention to the rapid radial motion of the bright component of the double star ζ Herculis, a second-type star of the third magnitude, which he found to be approaching the Sun at the rapid rate of 43 miles per second.

Dr. Bélopolsky's most important observations have been on the motions of the stars in the line of sight by means of Doppler's principle, in which branch of research he has followed in the footsteps of Professor Pickering and Dr. Vogel. He has devoted special attention to the variables β Persei *(Algol)*, β Lyræ, δ Cephei, η Aquilæ, λ Tauri, and ζ Geminorum. Dr. Bélopolsky's investigations have resulted in many extraordinary discoveries. In the summer of 1894 he

discovered, from the displacement of the spectral lines, that the star δ Cephei—a remarkable variable—is also a close double star, the companion being almost entirely dark. He concludes, however, that the variation is not produced by eclipse. He also discovered η Aquilæ—another remarkable variable star—to be a close double, as he found evidence of orbital motion in seven days four hours; but, as the times of minimum light do not correspond with those of eclipses in the hypothetical orbit, Dr. Bélopolsky concludes that the variations cannot be explained by the eclipsing satellite theory.

Perhaps Dr. Bélopolsky's greatest discovery in the "astronomy of the invisible" was that of another member in the system of *Castor*, or α Geminorum. *Castor*, which was first observed as a telescopic double by Bradley, has long been recognised as one of the chief binaries in the heavens. The secondary star revolves 'round its primary in a period to be measured by hundreds of years, while connected with the system is another smaller star at a greater distance. In 1896 Dr. Bélopolsky discovered by means of the displacement of the lines in the spectrum of the secondary that it is a close binary star, being attended by a dark companion. Both components revolve round their centre of gravity in about three days, with a velocity of about 20¾ miles per second, the distance between the two stars being about 85,400 miles. The system of *Castor* has been proved to be one of the most remarkable in the heavens, consisting of no fewer than four stars.

In a paper published in 1897 Dr. Bélopolsky discussed the problems presented by the variable star β Lyræ, the variations of which, although known for a hundred and twenty years, have never received a satisfactory explanation. In 1892 he was enabled to demonstrate that the diminution of the star's brightness is due to the diminution of the continuous spectrum. He also found that the bright line lettered F does not decrease at the time of minimum, proving that the body emitting the bright lines passes in front of the body giving the continuous spectrum. Some time later Dr. Bélopolsky again attacked the question. Dealing with only two spectral lines, those of

magnesium and hydrogen, he found that the system of β Lyræ is approaching the Sun at the rate of seven miles a second. He concluded that the lines are displaced "in a period identical with that of the star's double fluctuation." He found that the radius of the orbit of the primary star is 15,000,000 miles. He also concluded that the mass of the primary is eighteen, that of the companion, nine times the mass of the Sun. On the eclipse hypothesis the chief minimum coincides with the obscuration of the lesser star, and the lesser minimum with that of the primary, implying that the primary is much less luminous in proportion to its mass than its satellite. Professor Vogel, however, holds that the eclipse theory of β Lyræ does not explain the observations, and his view was shared by the late Professor Keeler.

Early in 1898 Dr. Bélopolsky discovered that ζ Geminorum is a close spectroscopic binary, a discovery which he did not publish at once, and which was made a year later by Professor Campbell at the Lick Observatory. Dr. Bélopolsky also paid much attention to λ Tauri. Photographs taken at Pulkowa showed the spectrum to become occasionally double. The astronomer found his materials insufficient to compute the orbit of the star. M. Bélopolsky has specially studied the radial motions of double stars, such as γ Leonis, γ Virginis, and 61 Cygni. His investigations of the latter star proved of much interest; he investigated its absolute velocity in space deduced from its motion in and across the line of sight. He found that the star's motion across the line of sight was $22\frac{1}{2}$ miles, assuming a parallax of half-a-second and a proper motion of a little over one second to be correct. Combining this with the motion in the line of sight, which he determined spectroscopically as 27 miles a second, he finds that the actual velocity of the brighter component of 61 Cygni is about 35 miles a second.

Dr. Bélopolsky struck out a new departure in the study of planets when he commenced investigating their rotations spectroscopically. He has studied the rotations of Jupiter, Saturn, and Venus. His period for Jupiter is somewhat less than that found by observations on the spots, but he explains

the discrepancy by a suggestion that owing to refraction in the atmosphere of Jupiter its diameter has been overestimated. He also observed the Rings of Saturn, and spectroscopically demonstrated the theory of their meteoric constitution, confirming the previous work of the late Dr. Keeler. The spectroscopic observations on Venus made by Dr. Bélopolsky in 1900 gave a very remarkable and perplexing result for the planet's rotation. According to M. Flammarion and others, the rotation of Venus probably takes place in twenty-four hours, while Professor Schiaparelli, Mr. Lowell, Sir Robert Ball, Professor Tacchini, and the majority of astronomers believe it to coincide with the period of the planet's revolution—namely, 225 days. Dr. Bélopolsky, from a determination of the rate at which various points on the globe of Venus were receding or approaching by the displacement of the spectral lines, found a period of twelve hours; but, as has been pointed out by Professor Newcomb, the absence of polar flattening on Venus is an argument against this view. The problem, however, cannot be regarded as solved; and the Russian astronomer regarded his spectroscopic investigation as merely approximate.

Dr. Bélopolsky's services to astronomy have been recognised all over the scientific world. In 1899 he received the Janssen Gold Medal from the Institute of France, while he was awarded two prizes from the Astronomical Society of St. Petersburg. In 1903 he became extraordinary member of the St. Petersburg Academy of Sciences. He has directed two eclipse expeditions —to the Volga in 1887, and to the Amur in 1896.

The astronomical world owes a debt of gratitude to Dr. Bélopolsky for his elaborate investigations in astronomy. His discoveries of spectroscopic binaries, his studies of variable stars, and his method of determining the rotations of the planets are sufficient to secure for him a permanent place in astronomical history. We owe many of the latest discoveries in "the astronomy of the invisible" to the indefatigable perseverance and skill of Russia's leading astronomer.

Percival Lowell.

Among the numerous fields of research offered by modern astronomy, one of the most fascinating is the study of the Inner Planets, our nearer neighbours in space. As we saw in a previous chapter Professor Schiaparelli, as the pioneer of that branch of astronomy, opened a new era in the study of these worlds. The observation of Mercury, Venus, and Mars has now passed into the hands of the American astronomers. Among them the most persistent observer of these planets is Percival Lowell.

Percival Lowell was born in Boston, March 13, 1855. He is of an illustrious family, directly descended from the original settlers of New England; and his father, Augustus Lowell, was a cousin of James Russell Lowell, the great poet. After careful education, Percival Lowell entered Harvard College, where he graduated in 1876. He received the Bowdoin Prize for an essay on "The Rank of England as a European Power between the Death of Elizabeth and the Death of Anne." He also delivered a lecture on the Nebular Hypothesis. In 1883 Mr. Lowell was one of the founders of the Mathematical and Physical Club of Boston. After this he travelled extensively in Japan and Korea, residing for several years in the former country. In 1883 he was appointed Foreign Secretary and Councillor of the Korean Embassy to the United States, and was one of the first foreigners in Korea where he was the guest of the Government. During his residence in Japan his love for the people and their customs

Percival Lowell

gained for him in return their honour and confidence. He was elected a member of the Asiatic Society of Japan. He founded on his recollections of travels in Japan and Korea his works—"A Korean Coup d'Etat" (1884), "Chöson: the Land of the Morning Calm" (1885), "The Soul of the Far East" (1886), "Noto: an Unexplored Corner of Japan" (1891), and "Occult Japan" (1894), besides several articles in the Transactions of the Asiatic Society of Japan.

Mr. Lowell became devoted to astronomy in 1870, when he began to observe the planet Mars, but it was not until 1894 that he founded the now famous Lowell Observatory at Flagstaff, Arizona. His first telescope was an 18-inch refractor by Brashear of Alleghany, Pennsylvania, but he afterwards procured a fine 24-inch refractor. The observatory, as he tells us in his preface to his book on Mars, was founded specially for observation on that planet at the time when it was exciting so much interest, and "for the purpose of getting as good air as practicable." Mr. Lowell points out that the location of observatories is a much more important matter than the size of instrument, and he wrote in 1895: "A large instrument in poor air will not begin to show what a smaller one in good air will. When this is recognised, as it eventually will be, it will become the fashion to put up observatories where they may see rather than be seen." In support of this, he remarks that Professor Schiaparelli, in the clear air of Milan, discovered the canals of Mars with an 8⅓-inch refractor, while the Washington 26-inch telescope has never yet shown them. Following the example of the great Italian astronomer, Mr. Lowell began his observations in the pure air of Arizona.

Observations on Mars were commenced on May 24, 1895. Unlooked-for discoveries were disclosed during the year in which the planet was kept under observation. Mr. Lowell was assisted by Mr. A. E. Douglass, formerly an assistant at Harvard Observatory, and Professor W. H. Pickering, of Harvard personally co-operated with him during the observations, and, indeed, erected the telescope. On June 3, 1894, Mr. Lowell measured the south polar cap of Mars, when it

stretched "almost one unbroken waste of white," over about fifty-five degrees of latitude, its diameter across measuring 2,035 miles. The snow-cap was kept under observation at Flagstaff until it ultimately disappeared. As it melted, there was seen surrounding it a broad blue belt, similar to that round the north polar cap, observed by Beer and Mädler in 1830. As the cap contracted in size, the belt grew smaller also, and in August it was, in Mr. Lowell's words, "a barely discernible thread drawn round the tiny white patch which was all that remained of the enormous snow-fields of some months before." On October 12, Mr. Lowell noted in his diary, "Polar cap has been very faint for some time; barely visible." The following day Mr. Douglass, his assistant, was astonished to find that it had vanished. This was the first time since man began to observe Mars that the snow-cap was seen to disappear. Mr. Lowell's observations of Mars were distinctly confirmatory of those of Professor Schiaparelli, of whom he is an enthusiastic admirer. Professor Schiaparelli detected 104 canals; Mr. Lowell has mapped about 350. At Flagstaff, also, confirmatory evidence was obtained of the existence of the double canals. Mr. Lowell paid great attention to the so-called "lakes" discovered by Professor W. H. Pickering in 1892. He mapped a large number of them, and noticed that they formed the meeting-place of numbers of canals. Rather than lakes, he termed them "oases," and, as Miss Clerke observes, "does not shrink from the full implication of the term."

Two important investigations were due to Mr. Lowell's able assistant, Mr. Douglass, one of the numerous rising astronomers of the United States. The first of these was the detection of canals in the dark regions of the planet or seas, finally disproving the theory of their aqueous character, on which grave doubts had been thrown in 1892. While measuring the planet's diameter, Mr. Douglass found that he had actually measured its atmosphere as well, proving beyond a doubt that Mars has an atmospheric envelope. Mr. Lowell and Mr. Douglass observed Mars persistently until April 3, 1895, when the favourable season for observation come to an end.

In the end of 1895 was published Mr. Lowell's work, "Mars," the result of his observations on the red planet. In summing up his work, he comes to the conclusion that Mars has an atmosphere, as is distinctly proved by changes on its surface and measurements by Mr. Douglass; that the dark regions of the planet are not seas, but marshy tracts of vegetation; that the polar caps are composed of snow and ice; and that the reddish-ochre portions of the planet's surface are desert land. He adopts Professor Schiaparelli's view that the canals are waterways lined on each side by banks of vegetation, as well as Professor W. H. Pickering's suggestion that the lines which we see are not the canals themselves, which are far too small to be seen, but the strip of fertilised ground surrounding them. In his chapter on the canals, Mr. Lowell propounds his startling theory of their nature, based on his own observations. He comes to the conclusion that the planet, owing to its small size, is scarce of water, and is dependent upon the melting of the polar cap for its annual supply. If there are inhabitants, they will be compelled to utilise every drop, and Mr. Lowell supposes the canals to have been dug by them to convey the water from the melting polar caps to the equatorial regions. The system of water-ways is planet-wide, and Mr. Lowell humourously remarks that party politics has had no part in its construction. The oases are supposed by him to be centres of population, where the inhabitants, driven from the desert lands by scarcity of water, cluster about the ground artificially fertilised. This is just what we observe on Mars. The canals grow darker as the cap melts, just as if water was being conveyed down. Mr. Lowell further considers that as Mars is an older planet than the Earth, and evolution on its surface further advanced, the inhabitants are probably in a higher state of civilisation. "What we see," he writes, "hints at the existence of beings who are in advance of, not behind us, in the journey of life."

In his recent work on "The Solar System," Mr. Lowell writes: "Life on Mars must take on a very different guise from what it wears on Earth. It is certain that there

can be no men there; that is as certain as anything well can be. But this does not preclude a local intelligence equal to, and perhaps easily superior to our own. We seem to have evidence that something of the sort does exist there at the present moment, and has made imprint of its existence far exceeding anything we have yet left upon mother earth." Mr. Lowell's hypothesis, which is further developed and supported in his work on "The Solar System," has not been cordially received among astronomers. Professor Schiaparelli considers that it "involves no impossibility." The leading astronomers of the day, with the exception of Professor Simon Newcomb and Mr. Maunder—who hold the canals to be optical illusions—have not expressed any definite opinion on the nature of the canals, although many minor writers have ridiculed the hypothesis. Nevertheless, Mr. Lowell's theory is gradually gaining popularity. He does not ask us to believe anything fantastic or extravagant. His hypothesis has been framed to account for all the various Martian features. At present we can only say that it is the most comprehensive and probable theory yet advanced to explain the phenomena of the red planet.

The study of Mercury was commenced by Mr. Lowell at Flagstaff in the autumn of 1896. Like Professor Schiaparelli, he observed the planet in daylight, when it was near to the Sun. He says in his work on "The Solar System" that at first he could make out no markings on the planet's surface. "It was only a pretty little moon nearly lost in the vast blue sky." However, he afterwards detected dark markings, and ascertained their relative fixity, confirming the previous work of Signor Schiaparelli. Mr. Lowell, in fact, ascertained that Mercury rotates on its axis in 88 days, exactly the same time required for its revolution round the Sun. To the Flagstaff observer the libration of the planet, however, in consequence of its uniform rotation and irregular orbital velocity, was obvious. Mr. Lowell formed a chart of Mercury, representing the markings discovered by him. Of these he says: "They were narrow, irregular lines, and very dark. They were not in

the least like the markings on Mars. There were no large patches of shade on the one hand, nor fine, regular pencillings on the other. Its lines were fairly straight, but broken and of varying width. 'Cracks' best explains their appearance, and probably their nature." No clouds or obscurations were visible, and the planet's markings represented "a geography in black and white," typical of a dead world, which Mr. Lowell concludes Mercury to be.

Mr. Lowell's observations on Venus followed those on Mercury. Professor Schiaparelli's observations and the conclusions which he drew from them have been confirmed at Flagstaff. Several maps have been drawn from Mr. Lowell's observations. It was found, from observations of certain markings, that the rotation of the planet was performed in about 225 days, exactly the period of the planet's revolution. In December 1900 Mr. Lowell ordered the construction of a spectrograph, in order to test the rotation of Venus by means of Doppler's principle. The observations were conducted by Mr. Slipher, Mr. Lowell's assistant. Mr. Lowell himself says of the investigation: "The evidence of the spectroscope is against rotation of short duration, and, so far as its measure of precision permits, the investigation confirms a rotation period of 225 days."

In 1902 Mr. Lowell was appointed Non-Resident Professor of Astronomy at the Massachusetts Institute of Technology. In December 1902 he delivered before the Institute a course of lectures which, in May 1903, were published in book form with the title of "The Solar System." It contains chapters on Our Solar System, Mercury, Mars, Saturn, Jupiter, and Cosmogony. Mr. Lowell's theory of the Martian canals is further supported in his recent work.

During the opposition of Mars in 1903 Mr. Lowell again observed the planet, and accurately determined the position of its axis. In the first *Bulletin* issued from the Lowell Observatory there is described an enormous projection observed towards the end of May by Mr. Slipher, one of Mr. Lowell's assistants. Mr. Lowell attentively observed the

projection, and wrote of it: "The thing that impressed me was its size. It was excessive both in length and in height." He then remarks that the projection was observed in the Martian tropics, and, from its colour, he concludes it to be, not a cloud of water vapour, but a cloud of dust. In the second *Lowell Bulletin*, reprinted in *Popular Astronomy* for August 1903, are recorded Mr. Lowell's observations on the north polar cap of Mars. On July 5, 1903, he made what proved to be the last measurement of the old north polar cap, and before it had vanished it was absorbed in the new cap which he observed in process of formation. After a discussion of the phenomena observed during the melting of the cap, he remarks: "It is worth noting that carbonic acid gas would not exhibit these phenomena, since, under such pressures as must exist in Mars, that substance does not melt, but passes practically instantaneously from the solid to the gaseous state."

In 1902 the idea occured to Mr. Lowell to utilise his drawings "to determine the degree of visibility of a given canal at different seasons of the Martian year," in other words, to discover whether any law regulated the apparent irregularities of the canals. Observations were made at Flagstaff from January 19 to July 26, 1903, and 372 drawings were secured. The observations were the most remarkable which have been made on Mars since 1894. Mr. Lowell was careful to eliminate all sources of possible error, such as the phases of Mars, axial rotation, different condition of seeing, etc., and he carefully examined the representations of each canal, making 8,500 separate determinations. The percentages of visibility of 85 canals were found. "Such a mass of data," says the American astronomer, "speaks for itself in the way of trustworthiness." The preliminary results were communicated in December 1903 to the American Philosophical Society. Mr. Lowell then resumed the investigation, examined other twenty-four canals, and raised the new determinations to 10,900. The results of these studies were published in 1904 in *Bulletin* No. 12 of the Lowell Observatory. Mr. Lowell was thus able to form a series of curves, which he calls

"cartouches," representing the visibility of the canals. They "proved to be in a state of flux. But the flood and ebb of their existence was not the same for all. Each waxed and waned in a way peculiar to itself; some had their minimum early, some late; some were constantly increasing, others steadily decreasing."

From a discussion of the cartouches or curves Mr. Lowell shows that they developed from the polar cap down to the equator, and into the opposite hemisphere. The development of the canals does not begin until after the polar cap begins to melt. Water is then set loose, and this causes a quickening of vegetal growth, the canals developing down the latitudes. This is further evidence that what we see is the strip of land fertilised by the canal itself. Mr. Lowell remarks that if we could view the Earth from some standpoint in space we should observe a wave of verdure sweep over the face of the planet, starting from the equator after the vernal equinox, and arriving in the arctic zone in summer. On Mars, on the other hand, the wave of verdure sweeps from the pole to the equator, and into the opposite hemisphere. The reason of this difference is the scarcity of water on Mars. While it is the Sun which is the primary cause of the terrestrial wave of vegetation, it is the water that plays the most important part on Mars. Mr. Lowell, from a discussion of the canals, concludes that it takes the water 52 days to travel from latitude 72 degrees N. to the equator, a distance of 2,650 miles. "This means a speed of 51 miles a day, or 2·1 miles an hour. And here we confront the surprising part of the performance, for the transference takes place in the face of gravity. . . . A particle of water or other liquid on the surface would know no inclination to move from where it found itself. Gravity would not solicit it to stir. Of its own accord it would not move from the pole to the equator." "Now," Mr. Lowell continues, "as it does flow towards the equator, and with a remarkably steady progression too, the inference seems inevitable that it has been carried thither by artificial means." Mr. Lowell says that his study of the canals in 1903 leads

him to the conclusions: (1) The canals develop down the latitudes after the meeting of the polar cap, the development proceeding across the equator into the planet's other hemisphere, and they do this alternately from either pole—these are the observed phenomena independent of any hypothesis. (2) The canals are, from their behaviour, inferably vegetal;—this results from the hypothesis we have found to fit the phenomena. (3) They are of artificial construction. Mr. Lowell points out that "the behaviour of the canals in action leads to the same view of their nature as their appearance at rest."

In his recent work on "The Solar System," Mr. Lowell points out a remarkable congruity in the distribution of satellites in the Solar System, and the distribution of the planets themselves. In the system of Saturn, Titan the largest satellite fills the centre of the field; and in the case of Jupiter and Uranus, the other systems available for examination, the largest satellites, Ganymede (Jupiter), and Titania (Uranus), occupy the central position. The same is true of the Solar System, as Jupiter, the largest planet, occupies the central place. But even this is not all. As Mr. Lowell remarks, if we construct a curve of positional sizes, we find that it has two maxima, a second lying inside the first. This place is filled in the Solar System by the Earth, in the Jovian by Io, in the Saturnian by Tethys, and in the Uranian by Ariel. The inclination of the orbits of planets and satellites is also discussed by Mr. Lowell. In the systems of Jupiter and Saturn the inclinations of the planes of the orbits of the satellites increase as the distance from the primary increases. In his own words: "The increase is regular. A smooth curve represents them all."

Mr. Lowell's opinions on the origin of meteoric stones are very remarkable. He considers that they must have originated in the molten interior of a sun. He points out that these stones cannot have come from other stars, and then, in the following impressive passage, he says: "They cannot have come from our present Sun, since it became a Sun, as their

orbits conclusively show. They must have come from the sun our system had, before the catastrophe, which caused the nebula which caused our Sun, occurred. They antedate the creation of the nebula itself which our nebular hypothesis points as the beginning of things. They are old with an age which staggers imagination; older in cycles of evolution, if not in years, than anything we see in the countless spangles of a winter's night in the blue-black firmament of sky. Before the silent tale they tell, history shrinks into yesterday, the Earth's career into the day before, and the evolving of the Solar System itself into modernity. Through that strange Widmanstättian fretwork that marks their surface like the lacing of frost-work on a window-pane, we seem to be gazing past the iron bars into the immensity, not of space alone, but of eternity."

Mr. Lowell discusses the evolution of the Solar System in a chapter in his book on the Solar System dealing with Cosmogony. To the remarkable congruities noticed by Laplace and his successors, Mr. Lowell adds six. These are: "All the satellites turn the same face to their primaries (so far as we can judge); Mercury and probably Venus do the same to the Sun; one law governs position and size in the Solar System and in all the satellite systems; orbital inclinations in the satellite systems increase with distance from the primary; the outer planets show a greater tilt of axis to orbit-plane with increased distance from the Sun (so far as detectable); the inner planets show a similar relation." Mr. Lowell leaves unsettled the question of the exact formation of the various planets; but his conclusions regarding the future of the Solar System are exceedingly striking and may be reproduced here: "Though we cannot as yet review with the mind's eye our past, we can, to an extent, foresee our future. We can with scientific confidence look forward to a time when each of the bodies composing our Solar System shall turn an unchanging face in perpetuity to the Sun. Each will then have reached the end of its evolution, set in the unchanging stare of death. Then the Sun itself will go out,

becoming a cold and lifeless mass; and the Solar System will circle unseen, ghost-like, in space, awaiting only the resurrection of another cosmic catastrophe."

Mr. Lowell is a Fellow of the American Academy, a member of the Royal Asiatic Society of Great Britain and Ireland, and a member of the Société Astronomique de France. He is also a member of the Astronomische Gesellschaft and the American Philosophical Society, and an honorary member of the Sociedad Astronomica de Mexico.

Mr. Lowell has done much for Martian observation, and has made it an almost distinct branch of astronomy. His ingenious hypothesis of intelligent life on Mars, even supposing it is ultimately rejected, remains a monumental contribution to modern speculative thought. And should it be confirmed, Mr. Lowell will take his place beside the great astronomical speculators. In the meantime, we may expect from Mr. Lowell further contributions to astronomy, and especially to the Martian branch, which will throw further light on the red planet. At all events, we may assert that Mr. Lowell, by his unwearied devotion to astronomy, has already gained for himself an enduring reputation.

Edward Emerson Barnard.

A BRILLIANT example of perseverance under difficulties is afforded by the life of Professor E. E. Barnard of the Yerkes Observatory, the discoverer of the fifth satellite of Jupiter and the photographer of the Milky Way. Like many other great astronomers, Professor Barnard began life in very humble circumstances, but, as has been well said in the "National Cyclopædia of American Biography": "His innate love of knowledge, coupled with an indomitable perseverance, have enabled him to become, not only well educated, but a shining light in the world of science."

Edward Emerson Barnard was born on December 16, 1857, at Nashville, Tennessee. His education consisted solely of two months at a local school, supplementary to home teaching by his mother, who was possessed of considerable ability. He was only eight years of age when he was compelled by poverty to work to a photographer in Nashville, where he remained for a considerable length of time. From his earliest years he was passionately fond of watching the stars, and, as a child, was deeply interested in their seasonal changes. In return for some pecuniary assistance, a youthful friend gave him a copy of one of Thomas Dick's astronomical works, which he read with great interest. He shortly afterwards purchased for himself a small spy-glass, and with it he observed the stars every clear night from the roof of the photographic gallery. Some time later he succeeded in constructing for himself a larger telescope, with which he nightly explored the heavens. Finally,

in 1877, he procured a 5-inch refractor, with which he began a series of observations on the planet Jupiter.

Professor Simon Newcomb, in his recently published "Reminiscences of an Astronomer," relates that, while presiding over the American Association for the Advancement of Science at its meeting in Nashville in 1877, he was informed that a young man of twenty, employed as a photographer, was desirous of making his acquaintance, being anxious to do something with his small telescope which might be useful to astronomy. Professor Newcomb, although he did not suppose that the young man could do anything more than amuse himself, suggested that he should begin to search for comets, which was the only field of research open to an observer placed as he was. Needless to say, the young man referred to was E. E. Barnard. The young astronomer followed Professor Newcomb's advice, and began in 1881 to search for comets, and on September 17 of that year he made his first discovery. In 1882 he found yet another comet, and in 1884 a short-period comet, with a period of over five years. The following year he found other two, in 1886 one, and in 1887 three more. By means of these discoveries he became known to the public as an enthusiastic astronomer.

In 1883, on being awarded a Fellowship in the Vanderbilt University, Mr. Barnard was enabled to leave his photographic business and devote himself entirely to astronomy. He was appointed to the observatory near the University, and attentively observed the heavens with the 6-inch equatorial. Meanwhile, he studied other subjects at the University, where he graduated in mathematics in 1887. Five times he won the Warner prize of two hundred dollars which was offered for cometary discoveries. In 1883 he discovered the binary character of β Capricorni while the star was undergoing occultation by the Moon. A star, which in even the largest telescopes appears as a mere point of light, vanishes instantaneously on occultation, but Mr. Barnard observed that, in the case of β Capricorni, several tenths of a second had elapsed before the occultation was at an end, and he concluded

the star to be double, an inference which was amply confirmed by direct telescopic observation. In the same year (1883) Mr. Barnard made another important discovery. Unaware that the "Gegenschein" or counterglow to the Zodiacal light had been discovered many years before by Brorsen, a German observer, he independently detected this wonderful phenomenon. According to the late Dr. Common, he estimates this discovery as a piece of his best work. On November 3, 1885, Mr. Barnard discovered a great nebula near ξ Persei.

On June 1, 1888, the Lick Observatory, on the summit of Mount Hamilton, California—the principal instrument of which, a 36-inch refractor, long held supremacy over all others—began activity. Professor E. S. Holden, Professor Newcomb's assistant at Washington, was the first director, and possessed great ability in selecting young men for positions in the observatory. Professor Barnard was also offered a position on the staff of the Lick Observatory, and he accordingly resigned his post at Vanderbilt University in 1888.

In 1889 Professor Barnard began, at the Lick Observatory, the brilliant series of observations which have rendered his name famous. He followed the fifth comet of 1889 for almost a year after it had become invisible to other observers; and he observed the first comet of the same year until it was 100,000,000 miles beyond the orbit of Jupiter, at a distance where no other comets had been observed. The comet discovered by Brooks, at New York on July 6, 1889, was attentively examined by Professor Barnard. He discovered it to be attended by four smaller comets. "The two brighter companions," he wrote, "were perfect miniatures of the larger comet, each having a small, fairly defined head and nucleus, with a faint, hazy tail. . . . To all appearance they were absolutely independent comets." Altogether, Professor Barnard has discovered sixteen comets, and is one of the greatest of living comet-hunters.

Perhaps Professor Barnard's greatest discovery was that of the fifth satellite of Jupiter. Since the time of Galileo, no addition had been made to the system of satellites surrounding

the giant planet. The Jovian system was regarded as perfect. During the exceptionally favourable opposition of 1892 Professor Barnard attentively observed the planet. Near midnight on September 9, 1892, he detected "a tiny point of light close following the planet." He at once suspected it to be an unknown satellite from the fact that it moved along with Jupiter; but it was soon lost in the glare of the giant planet, and could not be further observed that evening. The following evening was Professor Schaeberle's night with the 36-inch telescope, but he gave it up to Professor Barnard, who confirmed his observations of the previous evening. The existence of the new satellite was soon confirmed by other observers, among them Professor Young and the late Dr. Common, and further observations proved it to be closer to Jupiter than any of the other satellites, revolving round its primary in 11 hours 57 minutes, at a mean distance of 112,000 miles. The new satellite, which has received no name, is one of the faintest of telescopic objects, and indeed one of the smallest celestial bodies which can be seen with the telescope, its diameter not much exceeding 100 miles. It can only be observed with the largest telescopes in favourable climates. For this discovery Professor Barnard received in 1892 the Lalande Gold Medal of the French Academy of Sciences, in 1893 the Arago Gold Medal, and in 1900 the Janssen Gold Medal.

Professor Barnard has devoted much time to observations on the planets, especially Mars and Saturn. With the great Lick telescope he made, in 1892 and 1894, an extensive series of observations on the former planet, and published a series of drawings. His drawings do not always confirm the observations of Signor Schiaparelli and Mr. Lowell. The Lick astronomer observed the so-called "seas" to be broken up into a number of very fine details with the large telescope, while in smaller instruments they appeared as uniform patches of shade. Professor Barnard considers the polar caps to be composed of ice and snow; but, like the late Professor Keeler, he has been very cautious in giving any definite opinion on the condition of the planet.

Although Professor Barnard's greatest discoveries have been made with the telescope alone, unassisted by either spectroscope or camera, he has paid great attention to astronomical photography. While employed at the Lick Observatory, he was the first astronomer to discover a comet by photography, October 12, 1892. Since then, both at the Lick and Yerkes Observatories, he has photographed many comets. He has also secured magnificent representations of clusters and nebulæ. On a photograph of the Andromeda nebula, no less than 64,000 stars were visible; while he confirmed Professor W. H. Pickering's photographs of the Orion nebula. These photographs were, however, thrown into the shade by his magnificent representations of the Milky Way. His first photographs of the Galaxy were taken in 1889, and were secured not with the great refractor, but with the Willard lens of 6 inches aperture, no larger or finer than can be found in any magic lantern. "We must," said the late Dr. Common in 1897, when presenting to Professor Barnard the Gold Medal of the Royal Astronomical Society, "certainly admire not merely the skill, but the courage of a man who could, under the very shadow of the great 36-inch refractor, demonstrate the merits of a lens which could be bought for a few shillings."

Professor Barnard has photographed every portion of the Galaxy, and his photographs have brought out wonderful details. The stars in the Milky Way are shown to be mixed up with nebulous matter, so that the Galaxy would seem to be relatively the most youthful portion of the heavens, where the white stars of hydrogen and helium agglomerate, and where masses of nebulæ are to be found. "No feature of the Milky Way," says Miss Clerke, writing of Professor Barnard's photographs, "is more surprising than its inexhaustible variety. No 'law of condensation,' such as prevails in globular clusters, is there traceable. Each section follows its own method of aggregation. In one cloud-like forms are met with of the cirrus type; in another they recall breaking waves or tossing spray; again, groups of irregular bright spots alternate with extensive ramifications and rifts; here the

starry fabric is coarse-grained, there of microscopic fineness; while for heterogeneous scattering in many quarters there is substituted in others an apparently designed arrangement of the stars into rings, chains, and ellipses.". Referring to a photograph of the Galaxy in Cepheus, Professor Barnard remarks that the galactic light "is broken up into numerous black cracks or crevices. Looking at these peculiar features, I cannot well see how one can avoid the conclusion that they are necessarily real vacancies in the Milky Way, through which we look out into the blackness of space."

Professor Barnard began at the Lick Observatory an important series of observations on nebulæ. He has discovered a large number of these both by means of the eye and the camera. He discovered on November 30, 1888, in the constellation Cetus, a variable nebula, equal in brilliance to a ninth or tenth magnitude star, but in 1891 he found it to have lost four-fifths of its light. In 1889 he discovered another nebula, which he considered variable, as it could not have so long escaped detection.

In 1895 Professor Barnard, using the great Lick refractor, made a series of measurements on the asteroids. Both Sir William Herschel and Professor Pickering had agreed in placing Vesta as the largest of the group, having, according to the former, a diameter of 350 miles, and the latter of 319. These estimates, however, were made by photometric observations on Vesta's brilliancy and not by actual measurements with the micrometer. The Lick telescope, however, shows the little planets with discs, and Professor Barnard found that Ceres is the largest asteroid, with a diameter of 477 miles. Pallas comes second, with a diameter of 304 miles; Vesta third, 239 miles; and Juno fourth, 120 miles.

In October 1895, Professor Barnard resigned his post at the Lick Observatory to accept a higher position in the new Yerkes Observatory at Williams Bay, Wisconsin, where the great 40-inch refractor, the gift of Mr. Yerkes, the Chicago millionaire, had now been erected. In addition to this, he was appointed to a chair of astronomy in the University of Chicago.

The new observatory began activity in 1897, Mr. Barnard's connection with the Lick Observatory having ceased two years previously. In the same year Dr. Common, President of the Royal Astronomical Society, while presenting the Gold Medal to the great American astronomer, said: "Professor Barnard is in the presence of new opportunities, which we all feel sure will add to his triumphs. He has left Mount Hamilton, but he has only exchanged one big telescope for another, and when the Yerkes refractor is ready, we may confidently expect news from Chicago of the kind with which he has made us familiar in the past."

This prediction has been fulfilled. At the Yerkes Observatory, Professor Barnard has carried on the investigations which he commenced at Mount Hamilton. In addition to this, he has made an exhaustive study of the puzzling phenomenon known as the "Gegenschein," discovered by Brorsen in 1854, and by Professor Barnard himself in 1883. In a pamphlet, published in 1899, he devotes much attention to the "Gegenschein," which has been neglected by astronomers. He finds that the shape and brilliance vary at different seasons, and he suggests that the light is due to the reflection of rays of sunlight from meteoric bodies situated between the orbits of Mars and Jupiter, in opposition to the Sun.

On the morning of June 16, 1903, at 3 o'clock, Professor Barnard, observing Saturn with the 40-inch telescope of the Yerkes Observatory, noticed a remarkably bright spot on the planet's disc. The sky clouded over, however, and he could not again observe the spot until the morning of June 24. From observations of the spot he found that the rotation of the planet was performed in 10 hours 39 minutes, a period considerably longer than that found by Professor Asaph Hall from observations of a similar white spot in 1876. In a paper, read before the Chicago meeting of the National Academy on November 18, 1903, Professor Barnard discusses his observations of Swift's comet of 1892, Brooks' comet of 1893, and Borrelly's comet of 1903. Photographs of Brooks' comet showed that the tail which was one day in a normal

condition, was on the next "broken and disturbed as if it had encountered some resisting medium in its flight through space." Photographs of Borrelly's comet, taken on the night of July 24, 1903, showed that a large portion of the comet's tail was completely broken off. Professor Barnard considers that the repulsive action of the Sun will not explain these disturbances, and concludes that the two comets must have encountered some resisting medium, probably a swarm of meteors.

We have not space to describe in detail each of Professor Barnard's discoveries and investigations. His study of nebulæ, of variable stars, and of star clusters, his attentive scrutiny of the surfaces of the planets, have gained for him the position of one of the greatest astronomers of the United States. It is satisfactory to see that his services to science have been widely appreciated both in America and Europe. He is a member of the British Astronomical Association and of the American Association for the Advancement of Science. He is a contributor to the great German periodical, the *Astronomische Nachrichten*, and also to the *Astronomical Journal*, *Popular Astronomy*, and the *Monthly Notices* of the Royal Astronomical Society, of which he was elected a Fellow in 1887 and an Associate in 1898.

Professor Barnard occupies a unique place among American astronomers. He is not, like the late Dr. Keeler, purely a spectroscopic and photographic astronomer; nor does he give his attention solely to telescopic observations. His discoveries of the satellite of Jupiter and of comets, his photographs of the Galaxy, have gained for him a never-fading reputation. His scientific work has shed lustre on a country which has already produced many devoted students of the skies.

William Henry Pickering.

(Photo. by Pack Bros., Cambridge, Mass.)

William Henry Pickering.

THE greatest living observer of the Moon, and one of the greatest observers of the planets, is Professor W. H. Pickering of Harvard, brother of the distinguished director of the Harvard Observatory. Professor Pickering has already gained a great reputation, and his work places him in the foremost ranks of present-day astronomers.

William Henry Pickering was born in Boston on February 15, 1858. His father was Edward Pickering of Boston, and his brother is Professor Edward Charles Pickering, who is almost twelve years his senior. After training in Boston, W. H. Pickering entered the Massachusetts Institute of Technology, where he graduated in 1879. He observed the total solar eclipse of July 29, 1878, at Denver, Colorado, and contributed a paper on his observations to the *Monthly Notices* of the Royal Astronomical Society of London. On the completion of his university education he experimented with telephonic appliances in Boston, after which his attention was finally turned to astronomy. In 1886 he was one of those who observed the total eclipse of the Sun in that year from the West Indies. He observed the corona during the eclipse. The brilliancy of this mysterious appendage of the Sun proved to be only one fifty-fourth that of the average surface of the full Moon. During the eclipse of January 1, 1889, Mr. Pickering also secured photographs of the corona. In 1887 he was appointed assistant to his brother at Harvard Observatory, and in the same year he visited Colorado, in

order to select a suitable locality for an auxiliary station to Harvard, long contemplated by his brother. In the winter of 1888 Mr. Pickering paid a visit to California, and on Mount Wilson, near Los Angeles, he erected a temporary observatory, which his assistants occupied for over a year, securing several thousand photographs.

One of Mr. Pickering's most important photographs was that of the Orion nebula, taken January 14, 1890, with a 2-inch lens, the time of exposure being 6 hours, 22 minutes. This magnificent photograph quite revolutionised our ideas of the nebula, revealing the nebulous matter in Orion in its true form, that of a gigantic spiral, starting from near Bellatrix and sweeping round, past κ Orionis and Rigel, to η Orionis, probably joining with the great nebula surrounding θ Orionis. The entire constellation was thus shown by Mr. Pickering's photograph to be enwrapped in nebulous haze, while the original nebula in the "sword" is "but a pigmy" according to Professor Barnard, who confirmed Mr. Pickering's photograph some time later.

In 1888 Mr. Pickering turned his attention to the planet Mars, and suggested that the seas and canals of Mars were due to vegetation and did not imply the presence of large bodies of water on the surface of the planet. His observations of the canals suggested to him the idea that the lines which we see as canals are not actually the waterways themselves, which are much too small to be seen as such, but the strip of ground artificially fertilised by them. This view forms the basis of Mr. Percival Lowell's theory of intelligent life on Mars, which was discussed in the chapter on that distinguished astronomer. From Harvard Mr. Pickering observed Mars at its opposition in 1890. His assistants at Mount Wilson obtained a series of photographs on April 9, and on the plates the south polar cap was represented as of moderate size with a large dim area adjoining it. The following series of photographs, taken twenty-four hours later, revealed the dim area to be brilliantly white. Professor Pickering believed the cause to be an extensive deposition of hoar-frost.

In December 1890 Mr. Pickering was appointed assistant Professor of Astronomy in Harvard College, a position which he still retains. In the following year he erected the permanent auxiliary station to Harvard Observatory at Arequipa on the slope of the Andes, in Peru. It proved an ideal spot for an observatory. Professor Pickering remarks that in the absence of bright moonlight, eleven stars of the Pleiades can be constantly counted with the naked eye, the Zodiacal Light and its counter-glow the Gegenschein, which are in our latitudes such elusive phenomena, form a regular portion of celestial scenery; the Andromeda nebula is plainly visible to the naked eye, its apparent diameter exceeding that of the full Moon; and so pure is the atmosphere, and so free is it from haze or fog, that stars of the third magnitude are visible until their disappearance below the true horizon.

In this ideal spot, Professor Pickering commenced his important series of observations, securing many thousands of photographs. Visual observations were made on the Moon and planets, especially Mars at its favourable opposition in August 1892. The observations made at Arequipa were confirmatory of those of Professor Schiaparelli. Professor Pickering recognised the canals, just as the Italian astronomer had done; and, at the junctions of several canals, he detected round dark spots, called "oases" by Mr. Lowell, which he termed "lakes," in keeping with the general view that the green portions of the planet were actually water. Professor Pickering's observations, however, greatly weakened the idea that the dusky patches on Mars were really aqueous.

In 1893 Professor Pickering returned to the United States by way of the Straits of Magellan. The following year he erected the telescope for Mr. Percival Lowell at Flagstaff, Arizona; and during part of the year 1894, he personally co-operated with Mr. Lowell in observations on Mars. The polar sea, observed by Mr. Lowell, was made the object of careful study by Professor Pickering. He examined it with the Arago polariscope, and found it to be actually aqueous. He also

found that the light coming from the greenish areas showed no trace of polarisation, his observations supporting the opinion previously expressed by him, that the blue-green areas were not water but tracts of vegetation. Mr. Lowell adopts this hypothesis. Another curious fact noticed by Professor Pickering, in regard to the canals of Mars, was, that the linear separation of the double canals "was inversely proportional to the diameter of the object-glass of the telescope and directly proportional to the distance of the planet. In other words, if we use a telescope of twice the diameter, we shall find the same canals will measure only half as many miles apart. . . . The inference that I believe must be drawn from these facts is that, while the canals themselves are undoubtedly genuine, their doubling is an optical illusion."

In Professor Payne's periodical *Astronomy and Astrophysics* for 1893 and 1894, Professor Pickering described his observations on Jupiter's satellites. The first satellite (Io) was observed by him to be elongated in form, its longer axis being directed towards the centre of Jupiter, so that the satellite is not a sphere, but an ellipsoid. He considers that the rotation of the satellite is performed in 13 hours, 3 minutes. He found the rotation period of the second satellite (Europa) very difficult to determine, but reached the view that it is performed in over 41 hours. Professor Pickering's observations of Ganymede and Callisto, the third and fourth satellites, favoured the view that the times of their rotation and revolution coincide. Professor Pickering's observations of Jupiter, made at Arequipa, showed that the appearance of the planet is that of a uniform white mass of cloud, covered with a veil of brown material, which, says Professor Pickering, causes the belts; while he regards the white spots as openings in the layer of the brown material. "In short," he says, "it appears that, were it not for this insignificant light gauzy veil of brown cloud, we should find the surface of Jupiter, like that of most of the other planets in the Solar System, almost a perfect black. This gauzy structure must float in a nearly transparent atmosphere, surrounding and rising above it; it is this atmosphere which causes the

absorption and which almost completely obscures the belts at the limb of the planet."

As early as 1888 Professor Pickering, with a photographic telescope at Harvard, commenced a systematic search for new satellites of Saturn. The search was given up as unsuccessful, but he again resumed it when the Bruce telescope was set up at Arequipa. On developing some photographs of the planet taken on August 16, 17, and 18, 1898, Professor Pickering found on the plates a star-like object occupying different positions on different dates, just as a satellite would. The ninth satellite was found to be situated at a distance of nearly eight millions of miles from the planet, the time of revolution was fixed at about 490 days, and it received the name of "Phoebe." However, as the satellite was not observed telescopically and was not again photographed, many astronomers began to be sceptical as to its existence, one remarking that it "had gone to look for Vulcan." Even Professor Pickering himself "began to wonder if the four images discovered on the plates of 1898 might not after all have been defects or faint stars recurring by a curious coincidence in exactly the proper places to represent the motion of a satellite." On plates taken in 1900 the satellite could not at first be seen, but Professor Pickering, searching at a greater distance from the planet, found an object which ultimately turned out to be the satellite. Up to September 1902, sixty photographs of Saturn had been taken with the Bruce telescope at Arequipa, and on forty-two of these, Professor Pickering identified the new satellite, and an orbit was computed from the various measures. In April and May 1904, photographs of Saturn were taken at Arequipa ; Phoebe was not found in the predicted place, but at some distance from it. Professor Pickering again investigated the question, and, in the autumn of 1904, brought out the amazing result that the satellite revolves round Saturn in a retrograde direction, opposite to the motions of the other satellites. The eccentricity of the orbit of Phoebe is greater than that of any other satellite in the Solar System. From the recent measures, its distance

from Saturn—round which it revolves in 546·5 days—varies from 6,120,000 to 9,740,000 miles, and from its primary will appear only as a small star of the fifth or sixth magnitude. From photometric considerations, Professor Pickering computes its diameter at 200 miles.

This discovery may truly be called epoch-making. It has shown how photography aids us in detecting new satellites; while, from its retrograde motion, the satellite will be a theme of much interest to mathematical astronomers. Mr. A. C. D. Crommelin truly remarks: "There is no question that the discovery of Phoebe reflects the greatest credit on Professor W. H. Pickering. It was no mere accident, but the result of a deliberate search for additional satellites, which he has been carrying on for many years. Even after the existence of the satellite is known, it is a tedious matter to identify it on a photograph, but, to have discovered it in this way—one little grey dot among myriads of others—is, indeed, astonishing."

It must be admitted that it is in lunar astronomy that Professor Pickering has won his laurels. His views on the Moon's physical condition are not quite in accord with those of other distinguished astronomers; but, as he points out, all great students of our satellite such as Schröter, Mädler, Schmidt, and Elger, have been forced to admit the existence of change on the Moon's surface, while astronomers who have not paid special attention to it have declared it to be dead—a perfectly airless globe. An occultation of Jupiter witnessed by Professor Pickering at Arequipa, August 12, 1892, gave support to the view that a very tenuous lunar atmosphere does exist, a dark absorption band due, it was supposed, to a lunar atmosphere, being seen upon the disc of the planet. Professor Pickering made an exhaustive study of the Moon at Arequipa in 1892 and 1893, and reached the conclusion that certain changes did take place on the lunar surface. An expedition to the island of Jamaica in 1899 convinced Professor Pickering of the excellence of the climate for lunar observations. He points out that a steady atmosphere is

essential for the study of the surface of the Moon. With a five-inch refractor in Jamaica, he was enabled to see details quite invisible in the great telescopes at Harvard. In October 1900 he established near Mandeville, Jamaica, a temporary astronomical station, dependent on Harvard Observatory, where many excellent photographs were obtained, the first being taken a few minutes after midnight on December 31, 1900, the commencement of the new century Photographs were secured until August 31, 1901, when the telescope was dismounted. Totally, Professor Pickering and his assistants obtained eighty plates, covering five times the entire surface of the Moon. This appeared, as the first complete lunar atlas ever published, in Professor Pickering's monumental work, *The Moon*, which was published in New York in December 1903.

In this work, which must rank with Beer and Mädler's *Der Mond* and Schmidt's chart, as one of the most important contributions ever made to selenography, Professor Pickering sums up his observations on the Moon since 1891. He points out that the Moon has in all probably a very tenuous atmospheric envelope, not exceeding in density the one ten-thousandth part of our own. The chief gases of the terrestrial atmosphere, oxygen and nitrogen, could not be retained by our satellite on account of its small mass. Carbonic acid, however, which, as Professor Pickering remarks, "is to plants what oxygen is to animals," is probably to be found on the Moon, as is also aqueous vapour, which could only exist at the freezing point on a globe of the size of our satellite. This brings us to the subject of snow, or rather hoar-frost. Professor Pickering believes that snow is observed near the lunar poles and on the mountain tops, and this is certainly verified by his observations on some of the craters, especially Linné. In 1897 and 1898 he made a series of measurements on this crater, and especially on a halo of partly bright material surrounding it. The measures, however, were strangely discordant. The results seemed inexplicable at first, until it occurred to the Professor "to compare the

diameters of the area in question with the number of hours that it had been exposed, in each case, to the Sun. The whole matter then became clear. When the white spot first became visible, one and a half of our days after lunar sunrise, it was five miles in diameter. As the Sun rose, the spot rapidly diminished in size, until, one day after the lunar noon, it was only two and a half miles in diameter. From then till one and a half days before sunset, when it disappeared, it steadily increased in size, reaching a diameter of four miles. During the lunar night it must have continued to increase, until after sunrise it again became, as before, five miles in diameter. . . . The phenomenon is evidently analogous to that of the changing size of the polar caps of Mars or of our own Earth."

Several more recent investigations of the crater are distinctly confirmatory of this view, especially Professor Pickering's observations of Linné during lunar eclipses, when the light of the Sun is cut off, and the snow surrounding the crater should, theoretically, increase in size. During the eclipses of December 16, 1899, October 16, 1902, and April 11, 1903, the spot increased in size when obscured from the Sun. Professor Pickering brings forward evidence of the probable existence on the Moon of organic life, pointing out that the difference between the conditions of the Earth and the Moon is not so great as that above and below the ocean on our own planet; but he remarks that such life must be of a very low order as compared with that on the Earth. He has collected evidence of the existence of something resembling vegetation on the Moon, "coming up, flourishing, and dying, just as vegetation springs and withers on the Earth."

The "variable spots" on the Moon, first observed by Professor Pickering at Arequipa, clearly indicate the presence of vegetation. Special attention was devoted in 1901 to the crater Eratosthenes, in the floor of which were observed several dark markings resembling the canals of Mars, and which are almost certainly due to vegetation. Professor Pickering also concludes that "the evidence in favour of the

idea that volcanic activity upon the Moon has not yet ceased is pretty strong, if not fairly conclusive." He remarks in his atlas that the studies which he has described "will serve to illustrate what may be called 'the new selenography'—the selenography which consists, not in a mere mapping of cold dead rocks, but in a study of the daily alterations that take place in small selected regions, where we find real, living changes—changes that cannot be explained by shifting shadows or varying librations of the lunar surface."

As an astronomical investigator Professor Pickering occupies a leading place. He is now foremost among living observers of the Moon, and to his energy and perseverance we owe much of our knowledge of Mars, while his discovery of Saturn's ninth satellite has added to an already high reputation. Between them the brothers Pickering have enriched the entire science of astronomy with fresh discoveries and original investigations. While Professor E. C. Pickering occupies a high position in astrophysics, stellar astronomy, and photography of the stars, Professor W. H. Pickering has earned a lasting reputation in the study of the Moon and planets.

Julius Scheiner.

AMONG modern astronomers a high postition is occupied by Dr. Julius Scheiner, the distinguished astronomer of Potsdam, who is known to the scientific world as a careful and laborious investigator in spectroscopic astronomy. We owe much of our knowledge of various branches of spectroscopic and photographic astronomy—among them the spectra of bright stars, of the important nebulæ, and the radial motions of the stars—to the perseverance and energy of this great German astronomer, whose life and work we shall now attempt to describe.

Julius Scheiner was born in Cologne on November 25, 1858. After education in the Royal Gymnasium in his native city, he entered the University of Bonn in the spring of 1878 at the age of nineteen. While still a student he became devoted to astronomy, and the late Professor Schönfeld appointed him assistant in the Bonn Observatory. At the University, he devoted himself to mathematics and physics, as well as astronomy, and graduated as Doctor of Philosophy in 1882. His "dissertation," published at Bonn in 1882, was entitled "Untersuchungen über den Lichtwechsel Algols," in which he dealt with the problems presented by the famous variable star. From the observations of Schönfeld, one of the greatest authorities on variable stars, he deduced the duration of the partial eclipse as nine hours, forty-five minutes.

After six years' service at the Bonn Observatory, Dr. Scheiner was called to Potsdam Astrophysical Observatory as

Julius Scheiner.

(Photo. by Loescher & Petsch, Berlin.)

assistant in 1887. In the same year he assisted Dr. Vogel in his work on the radial motions of stars. The motion of each star was measured independently on the plates by both Dr. Vogel and Dr. Scheiner, and the mean of their results was used to denote the motion of the stars in the line of sight. Dr. Scheiner's name is connected with all Dr. Vogel's important spectrographic investigations. Dr. Scheiner's photographs of the spectra of bright stars, taken at Potsdam, are worthy of special mention. He devoted special attention to the spectrum of *Capella*, and measured 490 lines between the wave lengths 4124 and 4668. In his own words, he "believes a complete proof of the absolute agreement between its spectrum and that of the Sun to be thereby furnished." In his "Astronomical Spectroscopy" is given his list of 290 lines in the spectrum of *Capella*, with solar lines for comparison. Other yellow stars of the solar class, *Arcturus*, *Pollux*, and *Hamal*, possess spectra closely resembling that of the Sun, "thus furnishing," Dr. Scheiner remarks, "important evidence of the remarkable uniformity in the composition and development of the stars. But besides this, it also proves that this uniformity, for those stars in the same stage of development, extends also to the conditions of density and temperature, as well as to the percentage of composition of the different elements." The spectra of stars of the first type were also carefully examined by Dr. Scheiner, who reached some remarkable conclusions regarding the type of stars of which *Rigel* is an example. The lines in the spectra of these stars are remarkably broad and sharp, while, as a rule, broad spectral lines are also hazy. An examination of the spectrum of *Deneb*, in Cygnus, convinced Dr. Scheiner of its relationship to *Rigel*, although its visual spectrum is of the pure Sirian type.

On February 13, 1890, Dr. Scheiner announced an important discovery, which threw light on the connection between the Orion nebula and the chief stars of the constellation Orion, with the exception of *Betelgeux*. Dr. Scheiner discovered that a curious spectral line characterises both the stars and the nebula, only that, while bright in the nebular spectrum, it

appears dark in the spectra of the stars. This line was in 1895 identified by Sir Norman Lockyer, Professor Vogel and others with that of helium, detected by Sir Norman Lockyer in the Sun in 1868, and by Dr. Copeland in the Orion nebula in 1886. The Orion stars are presumably in an early stage of development, as helium is typical of both nebulæ and of youthful stars; and this idea is confirmed by Professor W. H. Pickering's photographs of extensions of the Orion nebula.

In 1890, Dr. Scheiner published his well-known volume, "Die Spectralanalyse der Gestirne," which was in 1893 translated, revised, and enlarged by Professor Frost, then of Dartmouth, New Hampshire, now of the Yerkes Observatory. In the preface to his work Dr. Scheiner remarked: "Hitherto no text-book has existed for this chief field of spectrum analysis—astronomical spectroscopy." This want was filled by Dr. Scheiner's magnificent piece of work, and his book is now a standard authority on spectroscopy. The volume is divided into four parts—spectroscopic apparatus, spectroscopic theories, the results of spectroscopic observations, and spectroscopic tables. In the third part of the volume Dr. Scheiner gives an admirable summary of the work of the leading modern spectroscopists. In this volume, he speculates on the distribution of the various types of stellar spectra. It has long been known to astronomers that the first type of spectrum is much more numerous than the second, which in its turn is more numerous than the third. Dr. Scheiner enquires into the reason of this difference. He writes: "Assuming the order of stellar development asserted by Vogel's classification to be correct, we may more exactly state the question in this way: 'why does the number of stars in a given stage constantly decrease as their condensation and cooling progresses?'" This might be answered, he remarks, by supposing the development of all the stars in the stellar system to have commenced at the same time; but this hypothesis breaks down for various reasons, and Dr. Scheiner suggests a very plausible explanation of the disproportion of the spectral types, which is confirmatory

of, and is confirmed by, the order of stellar development asserted by his colleague, Professor Vogel.

"If the Stellar System visible to us," says Dr. Scheiner, "is actually an island in the infinite space of the Universe, it can, despite the eternity of the Universe, have had its own beginning. It is not at all necessary that this beginning should have so occurred that all the stars should simultaneously reach the condition with which the idea of a star should be associated." Were the time occupied by a given star in passing each spectral type equal, these types would occur with equal frequency. But a star must occupy a longer time in passing through the condition most capable of condensation, "because," as Dr. Scheiner remarks, "the process of condensation itself develops an equivalent of heat for that lost by radiation, and therefore a high degree of temperature would be longer retained." The least condensed stars, those of the first type, possess the greatest capacity for condensation, while the second type is more condensed, and the third much more so. "On this hypothesis we can thus easily explain the disproportion of the different spectral classes, and possibly we might conversely reach some conclusions as to the relative length of time passed by the star in the different classes."

On September 9, 1891, Dr. Scheiner obtained, with the thirteen-inch photographic refractor of the Astrophysical Observatory at Potsdam, a plate of the great star cluster in Hercules known as Messier 13. This was the first plate on which the component stars were sufficiently well defined for the purposes of exact measurement. Accordingly, Dr. Scheiner prepared a catalogue of 833 stars in the cluster, the positions of which he fixed with great accuracy. In the words of Miss Clerke: "These fundamental stars, henceforward kept under watch and ward, will perhaps one day disclose the plan of their movements, and thus enable future astronomers to attack, with some possibility of success, one of the most arduous problems in celestial dynamics." In 1893 Dr. Scheiner published a drawing of the ξ Persei nebula, discovered by Professor Barnard in 1885. Dr. Scheiner's drawing was the

result of five photographs obtained with a small instrument of four inches aperture. He found that the ξ Persei nebula is not much smaller than that in Orion, and that its borders are more brilliant than its centre, which is comparatively obscure.

In 1898 Dr. Scheiner photographically determined the positions of seventy of the stars in the Orion nebula, which cannot but prove useful in a discussion of nebular proper motion. He compared the positions of stars as deduced from his photographic researches with earlier measurements by the late Dr. Gould. From the fact that the positions as measured by Dr. Gould and Dr. Scheiner at an interval of twenty years were practically the same, it was judged that the stars remained practically stationary—in comparison, that is, with the stars of the trapezium—and are not physically connected with either the trapezium or the great nebula.

In January 1899 Dr. Scheiner obtained a magnificent photograph of the spectrum of the Andromeda nebula, with an exposure of seven hours. Dark rays were seen, which interrupted the continuous spectrum, and Dr. Scheiner inferred them to correspond to the Fraunhofer lines in the solar spectrum. This points to the conclusion that the Andromeda nebula is actually a cluster of stars of the second type, too distant for the individual orbs to be visible. This conclusion, however, cannot be accepted without further investigation, as astronomers generally hold nebulæ similar to that in Andromeda to be actually gaseous, only in a further stage of their existence than the irregular nebulæ. Some reference must be made to Dr. Scheiner's researches on the Sun. He has devoted special attention to the dusky veil which is the cause of the darkening of the Sun's limb. In his work on the temperature of the Sun, which appeared in 1899, he suggested that the Sun's veil lies in the region of the chromosphere. He has shown that if the corona of the Sun is made up of meteoric particles, these must be raised to incandescence by the intense heat to which they are subjected.

Besides "Astronomical Spectroscopy," Professor Scheiner has published several other volumes. These are: "The

Photography of the Stars" (Leipzig, 1897), "Radiation and Temperature of the Sun" (1899), and "The Structure of the Universe" (1901). He has also published forty-four papers and has investigated the canals of Mars, photometry of the stars, and other astronomical subjects. He photographed the zone of the heavens—from 31 to 40 degrees north declination—for the International Chart of the Heavens, undertaken by the Potsdam Observatory. Recently, in conjunction with Dr. Wilsing, of the Potsdam Observatory, he undertook the measurement of the motion of nebulæ in the line of sight by means of Doppler's principle, and a paper on the subject was published in 1904.

In 1894 Dr. Scheiner became "Observer" in the Potsdam Observatory, and in 1900 Chief Observer. Since 1895 he has filled the position of Professor of Astrophysics in the University of Berlin. In 1901 he was elected an Associate of the Royal Astronomical Society. It would take too long to describe in detail each of Professor Scheiner's contributions to astronomical science. He has gained an enduring place in astronomy, not only by his own studies of the Sun and stars, but also through his share in Dr. Vogel's labours regarding stellar radial motion. Dr. Scheiner, by his various discoveries and investigations, has proved himself one of the most illustrious students of "the new astronomy."

William Wallace Campbell.

To the present director of the Lick Observatory we owe much of our knowledge of the motions in the stellar depths. By means of Doppler's principle of measuring radial motion, Professor Campbell has proved the existence of systems of stars for ever invisible to human sight. The name of Professor Campbell must rank with those of Professor Pickering, Dr. Vogel, and Dr. Bélopolsky among the astronomers who have opened up to science a new world, and who have grappled with the invisible.

William Wallace Campbell, the son of an Ohio farmer of Scottish descent, was born on his father's farm in Hancock County, Ohio, on April 11, 1862. He received his education first in common schools and at Fostoria High School, and for one year was a school teacher. In 1882 he entered the University of Michigan, where he graduated in 1886 with the degree of B.S., having specially studied mathematical astronomy. In 1886 he received the appointment of Professor of Mathematics and astronomy in the University of Colorado, where he remained for two years.

In 1888 Professor Campbell was recalled to Michigan University as Instructor in Astronomy, holding at the same time a position in the Detroit Observatory, where he devoted much time to the observation of comets and the calculation of their orbits. His reputation now increased rapidly, and in 1891 he was called to the Lick Observatory, California, as spectroscopic astronomer on the appointment of Professor Keeler to the

William Wallace Campbell.

(Photo. by Taber, San Francisco.)

Observatory at Alleghany, Pennsylvania. Soon after his appointment at Mount Hamilton the astronomical world was amazed by the appearance of a new star in Auriga. The star was attentively examined by Professor Campbell, who considered that the outburst was the result of the collision of non-luminous bodies. The star descended to the sixteenth magnitude in April 1892, and it was then supposed that the Lick observers had caught the last glimpse of it. On August 17, however, Professor Campbell found that it had increased to the tenth magnitude. He turned the spectroscope on the revived nova and found a velocity of approach of 128 miles per second on August 20. This was afterwards increased to 192 miles per second, and by November diminished to 100 miles a second. A green band in the spectrum of the nova was identified by Professor Campbell with the chief nebular line; indeed, he recognised eighteen lines in the spectrum of the new star as characteristic of planetary nebulæ.

Professor Campbell's spectroscopic observations of Mars proved of great interest. He was unable to detect the slightest difference between the spectra of Mars and the Moon, indicating that Mars has no appreciable atmosphere. Following out these researches, he concluded that the Martian atmosphere and any possible water vapour in it, could not be more than one-fourth as extensive as that of the Earth, and suggested that the polar caps were composed, not of snow and ice, but of consolidated carbonic acid gas. Ingenious, however, as the theory was, it has not been accepted. Professor Newcomb, indeed, remarks that, while not impossible, it lacks probability; while recent investigations by Mr. Lowell prove that the theory does not explain adequately the phenomena of the polar caps. Professor Campbell points out that the hypothesis was never seriously held. Sir William Huggins and Professor Vogel have both reaffirmed the presence of water in the Martian atmosphere.

Professor Campbell has specially studied the remarkable gaseous stars first observed by Wolf and Rayet of Paris in 1867. The brightest star of this class, γ Argus, of the second

magnitude, was first exhaustively investigated by Professor Campbell in 1893 and 1894. At Mount Hamilton the altitude of the star above the southern horizon is barely six degrees, and it can be observed only for a few minutes nightly. Nevertheless, Professor Campbell made a very minute study of the star and of the bands in its spectrum. He has studied thirty-two of the Wolf-Rayet stars; as Miss Clerke says, his observations "contributed materially to promote acquaintance with their peculiarities; yet they stimulated rather than satisfied curiousity."

All of Professor Campbell's studies have, however, been thrown into the shade by his magnificent work on spectroscopic binary stars, in which branch of research he has followed in the footsteps of Professor Pickering, Dr. Vogel, and Dr. Bélopolsky. Towards the end of 1896 Professor Campbell undertook at the Lick Observatory an important series of investigations on the radial motions of the stars. His observations were made with the great 36-inch refractor, to which was attached the Mills spectrograph, an apparatus presented to the Observatory by Mr. D. O. Mills, one of the trustees of Mr. Lick. Professor Campbell examined 285 stars, and a number of very important discoveries were made. In 1898 he found that *o* Leonis, of the third magnitude, is a spectroscopic binary system, revolving in fourteen days. In the same year he detected the variable velocity of χ Draconis. This star is of the third magnitude, and of the solar type. The period of the star's revolution appears to be 282 days.

In 1898 a still more important discovery was made at Mount Hamilton by Professor Campbell. He detected the variable velocity of the solar star η Pegasi, of the second magnitude, the period of which he found to be 818 days, or about $2\frac{1}{2}$ years, the longest period known in a spectroscopic binary. The shortest period in a telescopic double star is that of δ Equulei, which revolves in a little over five years. This proves that there is no actual distinction between telescopic and spectroscopic binary systems. Early in 1899 Professor Campbell detected the duplicity of the famous

variable star, ζ Geminorum, which Dr. Bélopolsky had discovered a year earlier, though he had not published his discovery. Professor Campbell pointed out, also, some remarkable circumstances regarding this star. To use the words of Miss Clerke, "the period of motion agrees with the period of light, but its rate varies oppositely to the brightness—that is to say, the star is moving rapidly in the line of sight just when its minima take place. They are, accordingly, not due to eclipses, which should coincide absolutely, or very approximately, with zero radial velocity."

The shifting of the spectral lines revealed to Professor Campbell in 1899 the composite nature of the Pole Star, which has a dark companion, the period of which proves to be four days; and the existence of a second dark companion was demonstrated. In the same year a considerable number of spectroscopic double stars were discovered. The most important discovery, however, was that of the binary character of *Capella*, which was detected early in 1900 by Professor Campbell, and three months later by Mr. Newall, of Cambridge, England. Dr. Vogel, at Potsdam, had shown *Capella* to be a typical star of the solar type, regular in its movements; and great surprise was expressed in the astronomical world on Professor Campbell's discovery. One of the stars composing the system of *Capella* is spectroscopically similar to the Sun; while the other, resembling *Procyon*, is presumably in an earlier stage of development. The revolution is performed, according to Professor Campbell, in 104 days. It became apparent that the duplicity of *Capella* might be observed telescopically; but the star was persistently seen single with the Lick refractor, although at Greenwich the image of *Capella* was observed to be elongated. Professor Campbell's researches brought to light some curious stellar systems. One of these is the telescopic binary κ Pegasi, discovered in 1900, the smaller component of which, besides revolving in eleven years, circulates round an invisible centre in six days. Another is β Capricorni, detected in 1899, one star of which is of the solar, and another of the Sirian type; yet another remarkable

system is revealed in the spectrum of *υ* Sagittarii, of the helium type.

Professor Campbell finds that of the 285 stars observed by him more than one in nine proves to be a spectroscopic binary. He comes to the conclusion that at least one star in five or six will be found to be spectroscopically double. He writes as follows: "The proven existence of so large a number of stellar systems differing so widely in structure from the Solar System gives rise to a suspicion at least that our system is not of the prevailing type of stellar systems. The new field of astronomical research thus opened up is of great richness, and may well occupy the attention, for an indefinite period, of the large number of observers and institutions now engaging in its development. . . . The measure of success attainable is dependent upon the degree of accuracy realised in the observed velocities." Totally, Professor Campbell has measured the radial motions of four hundred northern stars, and has detected sixty spectroscopic double stars.

Professor Campbell's study of the famous variable, *Mira* Ceti, deserves special mention. The maximum of October 1898 was a specially brilliant one, and Professor Campbell was enabled, with the aid of the Mills spectrograph, to determine the rate of radial motion; he proved it to be receding at the rate of its thirty-eight and a half miles a second. His investigations made it certain that orbital motion has nothing to do with the variations of *Mira*, which seems to be a solitary star. The variations must, therefore, be peculiar to the star itself; and this is probably true of all long-period variables.

In 1898 Professor Campbell led the Lick Observatory expedition which observed the solar eclipse of January 22 of that year at Jeur, in India. In 1900 he observed the great total eclipse in Georgia. On the lamented death of Professor Keeler, in August, 1900, Professor Campbell became acting director of the Lick Observatory, and since January, 1901, he has filled the post of director. One of his latest works has been the organisation of the Mills expedition from the Lick Observatory to Chile for the determination of the radial motions of all the bright stars

which cannot be observed from Mount Hamilton. On the summit of San Christobal, a hill one thousand feet in height, in the suburbs of Santiago de Chile, the expedition is now at work, and results of much importance are being obtained.

Professor Campbell's researches in astronomy have been recognised all over the scientific world, and numerous honours have been conferred on him. He has received several honorary degrees, among them LL.D from the University of Wisconsin, in 1902. He is a member of the National Academy of Sciences, of the Astronomische Gesellschaft, and Vice-President of the Astronomical and Astrophysical Society of America. He is a foreign member of the Spectroscopic Society of Italy, and was in 1901 elected an Associate of the Royal Astronomical Society. In 1903 he received the Lalande Prize of the Paris Academy. In addition to numerous scientific papers, published in the *Astronomical Journal*, *Astrophysical Journal*, *Astronomische Nachrichten*, *Publications* of the Astronomical Society of the Pacific and *Bulletins* of the Lick Observatory, Professor Campbell is author of a college text-book, *Elements of Practical Astronomy*, which entered a second edition in 1900.

The investigations of Professor Campbell have been the means of adding much to our knowledge of astronomy, and especially to that branch known as "the astronomy of the invisible." His perseverance has led to the discovery of numbers of invisible bodies and to the connecting-link between telescopic and spectroscopic binary stars. We may confidently expect from the famous American astronomer further discoveries in the line of research which he has made peculiarly his own.

Max Wolf.

Among the leading German astronomers of to-day a high place must be accorded to Dr. Max Wolf, of Heidelberg, the discoverer of over a hundred asteroids, and one of the most indefatigable astronomical photographers of modern times. Notwithstanding that he is still a comparatively young man, the name of Max Wolf must be placed among the most illustrious of modern astronomers.

Maximilian Franz Joseph Cornelius Wolf was born on June 21, 1863, at Heidelberg, where his father, Dr. Franz Wolf, was a physician. In 1879 he became devoted to practical astronomy, and, with the help of his father, erected a small observatory, where he observed planets and nebulæ, and where in 1884 he discovered a comet, which now bears his name, and which turned out to be periodical, revolving round the Sun in six years. It was last observed in 1898.

In 1888 Dr. Wolf took his degree in mathematics, and at the same time published a number of papers on physical subjects. In the following year he went to Stockholm to study the "perturbation calculus" under Gyldén. Here he remained until 1890, when he returned to Heidelberg, becoming a "privatdocent" in the university. He then gave up the study of theoretical astronomy, and devoted himself to astronomical photography. He found that in many ways short-focus lenses have many advantages over long-focus. In 1890 and 1891 he took his first photographs of the Galaxy. In the constellation Cygnus he photographed a very wonderful

Max Wolf.

(Photo. by Langbein & Cie., Heidelberg.)

region of the heavens. In addition to thousands of small stars, the photograph revealed a mass of nebulous light north of the star ξ Cygni; while α and γ of the same constellation were apparently involved in nebulosity. The importance of this discovery can scarcely be over-estimated. It showed that very probably the bright stars which are involved in nebulosity are still in process of formation. Indeed, Dr. Wolf concludes that the great mass of nebulosity embraces all the stars, bright and faint, in its vicinity.

Other important photographs of the heavens were secured by Dr. Wolf in 1891. One of these, of the constellation Cygnus, confirmed a previous naked eye observation by Mr. Gore. Another, of the constellation Auriga, showed the exact time of the appearance of the new star of 1892. On December 8, 1891, a photograph was taken by Dr. Wolf of the region surrounding χ Aurigæ, showing stars down to the ninth magnitude. There was no strange star represented in the photograph, but a plate exposed by Professor Pickering at Harvard two days later showed the new star as of the fifth magnitude. Dr. Wolf's photograph proved, therefore, that in the space of forty-eight hours, the star must have risen to the fifth magnitude from below the ninth.

Dr. Wolf's reputation as an asteroid discoverer is an enduring one. His name may be placed beside those of Piazzi, Olbers, Hind, Harding, Peters, Watson, Perrotin, Schiaparelli, and others, as a great discoverer of minor planets, and while these astronomers found asteroids in twos and threes, Dr. Wolf has discovered them in scores. He was the first to apply photography to the discovery of the asteroids. It occurred to him that an asteroid would, owing to its appreciable motion, be represented on a photographic plate as a trail, instead of a point of light like the stars. As Professor Brashear says: "When the picture is developed, the stellar images show themselves as small circular dots, but if a planet were in the photographic field during the exposure, its image would be that of a very short line or trail about one-twentieth of an inch long, because it has an average movement through

space of a little less than half the diameter of the Moon in twenty-four hours, while the stars remain practically stationary. This tiny trail is the clue to a new planet, or perhaps one already discovered."

On December 20, 1891, Dr. Wolf discovered the first minor planet by the photographic method, and for this discovery was awarded the Lalande Prize of the Paris Academy of Sciences. The new planet was named Brucia. In less than two years Dr. Wolf was enabled to discover seventeen asteroids, one of which was named after his native city of Heidelberg. It being quite conceivable that some of the trails might be due to defects in the plates, Dr. Wolf found it necessary to take more than one photograph of the same region of the heavens. At last he conceived the brilliant idea of constructing a double camera. When a trail is seen on two plates, in the same position relative to the stars, and taken at the same time, the existence of a new planet is abundantly demonstrated. He reconstructed his 6-inch telescope for this purpose in 1892. Two new 16-inch astronomical cameras were completed in 1900, and many new asteroids have already been discovered by them. On one occasion, no fewer than nine new asteroids were photographed at the same time.

By his photographic method, Dr. Wolf has discovered over one hundred asteroids, and each year brings new discoveries. A number of minor planets have been discovered by his assistants, Dr. Schwassmann, Dr. Carnera, Dr. Kopff, Mr. Dugan, and Herr Götz, and—by the same method—by M. Charlois, assistant to the late M. Perrotin at Nice. Several of the asteroids found by Dr. Wolf on his photographs have turned out to be planets already known, and he has therefore devoted much of his attention to the rediscovery of missing planets as well as the detection of new ones.

In 1893, Dr. Wolf was appointed Extraordinary Professor in the Heidelberg University, and in the same year he became director of the States Astrophysical Observatory at Königstuhl, Heidelberg, then in process of construction. At Königstuhl the majority of Dr. Wolf's astronomical discoveries have been

made. Probably his greatest investigations have been those on the Milky Way and nebulæ. His photographic plates revealed the existence of many new nebulæ, mostly planetaries. In 1901 he photographed many small nebulæ, of which a large number were apparently planateries, and they were distributed in groups in a manner not previously observed in such nebulæ. In March 1901, Professor Max Wolf's photographs revealed to him an actual cluster of nebulæ, or "nebelhaufen," surrounding the star known as 31 Comæ Berenices, although probably not associated with it; 108 nebulæ, some elongated and others roundish, were found in a space only thirty minutes of arc in diameter. Another group, also detected by Professor Wolf, appears to cluster round η Virginis. In 1901, Professor Wolf commenced to publish lists of the faint nebulæ found and measured on his plates. On August 22 and 23 of the same year, Professor Wolf took photographs of Nova Persei, and detected faint nebulous masses to the south-east. He suggested, also, that the star should be photographed with larger instruments, a suggestion which was at once acted upon, with the result that a great nebula was discovered by the American astronomers. Professor Wolf explained the expansion of the nebula indicated by the American photographs as caused by the propagation of electric waves of the Hertzian type; in opposition to Professor Kapteyn and Professor Seeliger, who regard the expansion of the nebula as an illusion.

Of especial interest are Professor Wolf's researches on the distribution of nebulæ. In 1902, he published a catalogue of 1,528 nebulæ round the pole of the Galaxy, which showed a systematic distribution of these remarkable objects. In 1903, he followed up his researches, and in his own words "found that there exists a law for the Milky Way nebulæ, producing holes in the crowds of Milky Way stars." In a recent paper, he details his interesting discoveries regarding the distribution of nebulæ and the stars surrounding them. Investigations at the Königstuhl Observatory have shown Professor Wolf that all extended nebulæ "are situated in the interior of regions

containing only a very small number of faint stars." "The two great Orion nebulæ," Professor Wolf continues, "as well as the North America * nebulæ in Cygnus, are surrounded by and are situated at the edge of regions nearly void of faint stars. My assistant, Mr. Kopff, has published an exact enumeration of the stars about these objects, from which it is proved that nearly all faint stars have disappeared from the immediate surroundings of these nebulæ, though they are ten times more numerous both in the nebulæ themselves and far outside." The nebulæ Messier 8 and 20, in Sagittarius, γ Scuti, β Cassiopeiæ; the great nebulæ north of *Antares* and near γ Cygni, and many others, show this relation. Professor Wolf has also shown that "though partially or wholly surrounded by void zones, the nebulæ are generally placed at the end of a longer extended lacuna, so that we are led to the impression that we see the result of some cosmic movement, the end of the lacuna showing the place where this unknown event began."

We now come to Professor Wolf's remarkable investigations by means of the stereo-comparator. The application to astronomy of this contrivance may be described as a very important addition to the astronomical instrumental equipment. As is well known, by the stereoscope we are enabled to observe objects in relief, that is, at their proper relative distances. But the old stereoscopes possess a very limited range. Some time ago, an instrument was constructed by the eminent German optician, Dr. Pulfrich, of Jena, which he named the "stereo-comparator." If two photographs of a moving object are combined and examined by the stereo-comparator, the object will be seen in its proper position relative to other objects, even though that object may be a lunar mountain or a minor planet. Professor Wolf, in August 1901, conceived the idea of applying the stereo-comparator to astronomy. Two photographs of Saturn, taken at Königstuhl on June 9 and 10, 1899, were examined, and the planet and two of its

* This nebula was so named by Professor Wolf, from its resemblence to the map of North America.

satellites appeared suspended in space, far in front of the background formed by the stars. Professor Wolf, by way of experiment, submitted to Dr. Pulfrich a plate on which several asteroids had been recognised after a careful search. Dr. Pulfrich recognised the asteroids suspended in space after a few minutes' comparison, although quite unaccustomed to examining astronomical photographs, and, in addition, pointed out another asteroid which Professor Wolf had not observed.

After 1901 Professor Wolf commenced regular observations by means of the stereo-comparator. In 1902 he applied the new instrument to the tails of comets, and satisfied himself that they are really turned away from the Sun. In 1903 he discovered by the new method—besides many asteroids—fifty new variable stars, easily recognised because, as M. Van Biesbroeck has remarked, "they distinguish themselves by a sort of scintillation contrasting with the tranquil and steady light of the background." Twenty-four of these new variables prove to be in the Orion Nebula, thus giving the hint that nebulæ will prove to be as prolific in variable stars as star-clusters. It is true that this is only a beginning, but it is an admirable one, and the researches of Professor Wolf have shown how much may be done with the stereo-comparator. For the proper motions of the stars and nebulæ, for their radial motions and for stellar parallax, the new instrument will probably be invaluable, while defects in the photographic plates are also observed. It may be here pointed out that while the telescope shows us the celestial bodies as if they were projected on a flat sphere, the stereo-comparator has already, in the able hands of this brilliant and original German astronomer, shown the planets as actually suspended in space, and what it may yet show us in regard to the positions of the stars cannot be predicted. To quote M. Van Biesbroeck: "The different experiments, where stereoscopy has been put in practice, have appeared up to this time so convincing that one can hardly prophecy yet where the application of the new method will end."

It would take too long to describe in detail each of Professor

Max Wolf's individual discoveries and investigations. In 1900 he constructed his new instrument, the "Schnittphotometer," with which he measured the axis of the Zodiacal light; while his discoveries of variable stars and nebulæ further increase his reputation. His investigations have been recognised all over the scientific world. Since 1894 he has been a Fellow of the Royal Astronomical Society, and in 1903 was elected an Associate. In 1900 he was offered the chair of Astronomy at Göttingen, in succession to the late Professor Wilhelm Schur, but he declined the offer, preferring to remain at Heidelberg. For this he was nominated Privy Councillor of the Duchy of Baden. In 1902 he was appointed Ordinary Professor of Astrophysics and Geophysics in Heidelberg University.

Astronomy owes much to Professor Wolf. He occupies the supreme place among modern asteroid hunters; his discoveries of new nebulæ and his studies of the Milky Way give him an exalted place among the students of the Stellar Universe; while his varied investigations have done inestimable good to astronomy. The illustrious astronomer of Heidelberg is still a comparatively young man, and we may confidently expect further contributions to astronomical science; but he has already secured an enduring reputation as an inventive genius and a brilliant discoverer.

THE END.

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